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FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program (FFIP), a multidisciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Islands forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the Islands and prompted the establishment of the 5-year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining the improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines and helicopters, and by logging planning to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests and Lands (Research Branch), and the B.C. Ministry of Environment and Parks (Fisheries Branch). Participating agencies include the Canadian Forestry Service (Pacific Forestry Centre), and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

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For information about the program contact Ministry of Forests and Lands, Research Branch, 1450 Government Street, Victoria, B.C. V8W 3E7.

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ABSTRACT

The effects of mass wasting, primarily debris torrents, on salmonid juvenile rearing habitat in streams on the Queen Charlotte Islands were assessed in 1981-1982 with a synoptic survey of 44 streams, followed later by a more detailed survey of seven streams in 1983-1984. Streams in the synoptic survey included both logged and unlogged streams, whereas only logged streams were included in the detailed survey. While it was not the intent of the study to assess the effects of logging *per se* on stream habitats, where appropriate, changes attributed to logging alone are also described.

Substantial reductions in both the quantity and quality of fish rearing habitat were found in first and second order perennial streams affected by debris torrents. The greatest impacts occurred in streams below 7% gradient, the general upper limit of habitat utilized by species such as coho salmon. In these zones, debris torrents reduced average net pool depth by an estimated 20-40%, pool area by 38-45%, and undercut bank cover by 76%. Large organic debris (LOD) cover was also reduced by 57%, primarily because of a reduction in the number of LOD pieces present, and shifts in the orientation and position of LOD relative to stream flows. Other major changes included a significant increase in rooted stream width due to excessive scouring in sediment transport zones, and infilling and lateral channel movements in deposition zones. Dewatering reduced wetted stream width.

A comparison of winter and summer cover characteristics of torrented and non-torrented streams revealed that while summer cover properties changed as a function of torrenting there was no difference in total summer cover area between stream types. This was attributed to a shift from the rootwads, coarse woody debris, undercut banks and deep water cover types found in non-torrented streams to rock and boulder cover associated with surface turbulence in torrented streams. Winter cover characteristics included pools with woody debris, undercut banks and deep-water where fish could seek refuge from high velocity stormflows. These features were reduced in torrented streams by 79%, and by 50% in intermediate streams (flood damaged and partially rehabilitated torrented streams). In the most severely affected stream studied the total amount of suitable overwinter habitat in the entire accessible portion of stream averaged 0.4% of the stream area, compared to 17.8% in non-torrented streams — a decline of 98%.

Torrented streams had not only less cover overall than non-torrented streams, they also exhibited a more restricted range of habitats. There were no undercut banks associated with pools controlled by woody debris in any of the torrented reaches examined, and only rarely were rootwads present. In addition, woody debris cover located in pools of non-torrented streams was almost always associated with abundant deep-water cover. In contrast, pools associated with woody debris in torrented streams were comparitively small and shallow in relation to the amount of debris present.

Seventy-three percent of pools in non-torrented reaches were formed by scouring around LOD, compared to only 40% of pools in torrented reaches. Boulders, in contrast, accounted for 46% of the pools scoured out in torrented reaches, but only 13% on non-torrented reaches. Where non-torrented streams usually had a complex assemblage of LOD controlled lateral scour, plunge, backwater, and dammed pools, torrented streams typically had only simple lateral scour and cascading 'pocket-type' pools.

When they first occur, debris torrents affect, on average, the upper two-thirds of the habitat available to anadromous fish in first- and second-order logged streams. Significantly less habitat is affected in unlogged streams. Downstream of directly affected stream reaches, there were no obvious changes to fish rearing habitat, apart from those caused by logging. From the synoptic survey data, effects attributed strictly to logging included a 27% reduction in woody debris cover or about half the amount removed by mass wasting, and a 74% reduction in undercut bank area about the same removed by mass wasting.

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1 INTRODUCTION

During the fall-winter period of 1978-1979, frequent high intensity rain storms resulted in extensive mass wasting across much of the Queen Charlotte Islands. Preliminary surveys undertaken in the Rennell Sound area on the west coast of the "Charlottes" (Schwab 1983) indicated that many of the failures were probably induced by logging, an observation that has since been confirmed for the Charlottes as a whole, wherever steep-slope logging is practised. Gimbarzevsky[1] and Rood (1986), for example, both report that the dominant geomorphic process present in the hilly plateau and mountain regions of the Charlottes is mass wasting. Rood further reports that the frequency with which mass wasting occurs in logged areas has increased 34 times over unlogged areas, while the amount of mass wasting related sediments entering streams has increased 43 times.

Slope failures which occurred as debris flows, debris slides, and torrents in headwater areas were especially damaging because they frequently introduced large volumes of eroded material into salmon and trout streams, altering channels extensively. At the time of the 1978-1979 winter storms, the effects of mass wasting on stream habitats and fish were not well documented. Although land managers were concerned that logging-related slides were damaging fishery resources, the exact nature or extent of the damage was not well understood.

The British Columbia Ministry of Forests and Lands, B.C. Ministry of Environment and Parks, and Canada Department of Fisheries and Oceans have attempted to resolve issues concerning the effects of steep-slope logging on forest land, and develop prescriptive solutions for avoiding or minimizing landslide damage. Accordingly, the Fish/Forestry Interaction Program (FFIP) was initiated in 1981 (Poulin 1984). This 5-year interdisciplinary study is an applied research program that has involved the co-operation of geographers, geomorphologists, hydrologists, logging engineers, silviculturists, and fishery biologists to quantify the impact of logging-induced mass wasting on streams and forest land.

The fisheries studies conducted under FFIP from 1981 to 1984 were designed primarily to provide information that could be used to assess the impacts of mass wasting on the salmonid populations of Queen Charlotte Islands streams. While detailed studies were eventually conducted in considerably fewer streams, the study started as a synoptic survey of 44 watersheds in which various aspects of the juvenile rearing and egg incubation environments were examined. Three major objectives of the study were:

1. to compare the amount and type of fish rearing habitat present in streams with and without mass wasting;
2. to describe the substrate composition and stability of fish spawning habitats in streams with and without mass wasting;
3. to determine the overall effects of mass wasting on egg-to-fry survival, juvenile survival, and smolt production of each major species.

This report presents the results of the investigations carried out to meet the first objective, and examines the changes in quality and quantity of salmonid rearing habitat attributable to mass wasting. Where appropriate, differences attributed to logging alone have been isolated and discussed, although assessing logging impacts per se was not the focus of this study. The impacts of mass wasting on spawning habitat and salmonid egg-to-fry survival (objective 2)[2], and the influence of mass wasting on juvenile fish growth, survival, and smolt production (objective 3)[3] will be presented in separate reports.

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[1] Gimbarzevsky, P. 1986. Mass wasting on the Queen Charlotte Islands: a regional overview. B.C. Min. For. Lands, Land Manage. Rep. No. 29. In Prep.

[2] Tripp, D.B. and V.A. Poulin.(1986a). The effects of logging and mass wasting on salmonid spawning habitat in streams on the Queen Charlotte Islands. B.C. Min. For. Lands, Land Manage. Rep. In Prep.

[3] Tripp, D.B. and V.A. Poulin.(1986b). The effects of logging and mass wasting on salmonid juveniles in streams on the Queen Charlotte Islands. B.C. Min. For. Lands, Land Manage. Rep. In Prep.

2 STUDY AREA

The Queen Charlotte Islands are a scimitar-shaped archipelago of some 150 named islands located 100 km off the north coast of British Columbia, just south of the Alaska Panhandle (Fig. 1). Surrounded by Pacific waters, the Charlottes are largely isolated from cold continental air masses originating on the mainland to the east, but are directly exposed to changeable Pacific air masses from the west. Combined with the rugged topography of the islands, these factors result in a climate described by Calder and Taylor (1968) as having "...very cool summers, very mild winters, a prevalence of cloudy skies and strong winds, and excessive late fall and early winter precipitation." The Islands have a unique climate found in only 1% of Canada, with mean annual precipitation ranging from 1150 mm at Sandspit on the east coast to 4200 mm at Tasu on the west coast (Toews and Wilford 1978).

The Charlottes are divided into three major physiographic regions (Fig. 1): 1) the Queen Charlotte lowlands comprising roughly the northeast half of Graham Island; 2) the Skidegate Plateau covering the central portion of Graham Island from the northwest to the southeast and the northeastern portions of Moresby and Louise islands; and 3) the Queen Charlotte Range including all of the small southern islands, the rest of Moresby Island, and the southwest corner of Graham Island (Sutherland Brown 1968). Bedrock geology is largely dominated by volcanics and fossiliferous marine sedimentary rocks, frequently exposed or mantled by a thin cover of glacial and colluvial material (Sutherland Brown 1968) and subject to deep and rapid weathering (Alley and Thomson 1978). The soils are mainly ferro-humic podsols, with extensive occurrence of organic and lithic soils (Farley 1979).

Streams draining the Islands' forest land base provide valuable habitat for British Columbia commercial and sport fish resources. Charlotte streams are probably best known for their runs of pink (even-year), chum, and coho salmon. Total estimated escapement of these species is about 1.3 million, or 13%, of the provincial total (Pearse 1982). Chinook and sockeye salmon are present on the Charlottes but have a much more restricted distribution, and account for only 1 and 0.1%, respectively, of the total provincial escapement. Other salmonids that use Charlotte streams include steelhead trout, Dolly Varden char, and cutthroat trout.

In total numbers, the largest share of the Islands' fish production is derived from a relatively small number of short coastal rivers that drain the largest watersheds of Graham and Moresby islands. Twenty streams account for an estimated 65% of the total commercial salmon production. The remaining production comes from the characteristically steep, very short, headwater streams that originate throughout the Queen Charlotte Ranges, and the dissected hillslopes of the Skidegate Plateau. In total, some 350 streams drain the steeplands of the Charlottes, and of these, 94 % are first- and second-order stream systems (Northcote *et al.* 1984). It is in these watersheds that much of the steep-slope logging is currently being conducted. Nearly 200 of these streams are known to contribute to the annual production of salmon.

2.1 Study Stream Characteristics

In this study a total of 44 streams, encompassing 65 reaches with varying mass wasting and logging histories, were examined (Fig. 1). Most streams (N=29) were located in the Queen Charlotte Range, and the remainder on the south/southwest portions of the Skidegate Plateau. Streams in the northwest and northeast portions of the Skidegate Plateau were not sampled, nor were any in the Queen Charlotte Lowlands. Generally, the smallest and steepest basins occurred around the south Moresby region in the Queen Charlotte Range, while the larger and flatter basins occurred on northern Moresby, and on Graham Island on the Skidegate Plateau. In the latter region, watershed areas ranged from 1.5 to 47.5 km^2, averaging 13.5 km^2, while those in the Queen Charlotte Range ranged from 0.5 to 19 km^2, averaging 5.5 km^2. Overall mean watershed area was 8.2 km^2. Stream gradients ranged from 0.8 to 12.4%, averaging 4.1 ± 2.8% (± 1 SD) overall.

Twenty-two streams were sampled in 1981, almost all on Louise, Talunkwan, and Lyell islands, and the central and northeast portions of Moresby Island (Fig. 1). In 1982 sampling was

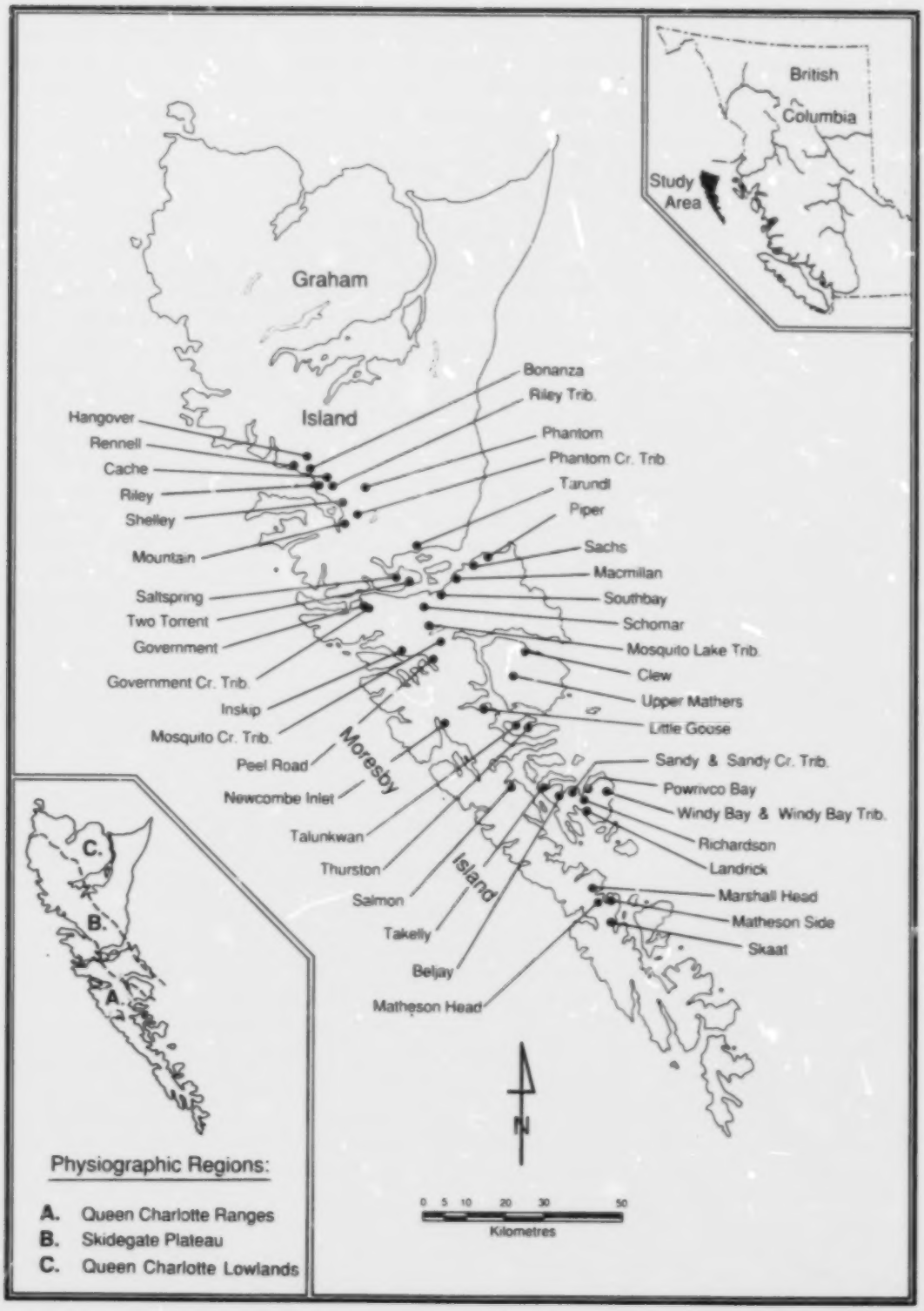

FIGURE 1. The study area showing location of streams sampled on the Queen Charlotte Islands, 1981 to 1984.

expanded to include an additional 22 streams, including streams on the southeast and west coasts of Moresby Island, streams in the central Skidegate Inlet/Channel region between Graham and Moresby islands, and streams on the west coast of Graham Island in Rennell Sound. In 1983-84, sampling was confined to seven streams, three with debris torrents (Macmillan, Saltspring, and Southbay Dump) and four without (Piper, Schomar, Schomar tributary, and Tarundl). All but one (Schomar tributary) were sampled previously in 1981 and/or 1982 and all were located in the central Skidegate Inlet/Channel region.

2.1.1 Logging history

The study reaches exhibited a wide range of logging histories (Tables 1-3), including those that were unlogged (N=20), those logged over 15 years ago (N=32), and those logged within the past 15 years (N=13). Stream reaches classified as having been logged more than 15 years ago (i.e.,"old" logging) were reaches generally logged to the streambanks with A-frame, skidder, or high-lead cable systems. Yarding operations invariably involved extensive cross-stream yarding. In many cases, instream yarding and skidding were also prevalent. Today, most of the riparian zone in these old logged stream reaches is dominated by a heavy growth of red alder that, in the absence of mass wasting, typically forms a dense canopy over the stream channel. Average age of the logged reaches designated as old was 22 years, dating back from 1918 to 1966. Most old logged reaches also had recent logging upstream.

Stream reaches classified as having new or recent logging were logged an average of 7-8 years ago, dating from between 1968 and 1981. While most were located in headwater areas above older logging sites, they also included drainages without any previous logging, e.g., Riley and Bonanza creeks in the Rennell Sound area on the west coast of Graham Island. High-lead cable systems with roads were used in all newly logged areas, and timber was typically fallen away from the stream with little or no cross-stream yarding. Buffer strips were occasionally left at one side along with any timber that had accidently fallen or blown down into the stream. Unlike in the old logged stream reaches, dense alder growth was not usually a dominant feature of the riparian zone, either because logging was too recent for alder to be established or because the natural streamside vegetation was left intact. In some areas, silvicultural measures such as girdling or poisoning have been used to control alder. Stream gradients in recently logged, old logged, and unlogged reaches were similar and averaged 4.2% (range 0.9-10.0), 3.9% (range 0.8-12.4), and 3.9% (range 1.1-9.9), respectively ($P>0.05$). Total basin area logged was also similar: 36% for old logged reaches (range 8-82%) and 35% for recently logged reaches (range 3-77%).

2.1.2 Mass wasting

Mass wasting in streams also varied considerably over the study area. Of the 65 stream reaches selected for study, 24 (21 logged and 3 unlogged) were directly affected by some form of recent mass wasting, while 17 (11 logged and 6 unlogged) had mass wasting upstream. Debris torrents as defined by Church (1983) were the most common form of mass wasting investigated, occurring within or upstream of 37 study reaches since 1972, 28 of them since 1978. Large sediment accumulations, caused by bank destabilization after logging and since exacerbated by more recent bridge failures, slides, and sudden shifts in the sediments (Roberts 1984), resulted in torrent-like conditions in two study reaches. Recent slides from steep adjacent hillslopes created torrent-like conditions in two other low gradient reaches. The average stream gradient of study reaches directly affected by mass wasting (5.2% ±3.1%, N=25, range 0.9-12.0%) was higher ($P<0.05$) than those with no mass wasting (3.4-2.3%, N=40, range 0.8-12.4%). Though highly variable, the amount of basin area logged was also higher ($P<0.05$) in streams with mass wasting (29-27%, N=22, range 0-82%) compared to those without (13-15%, N=18, range 0-72%).

2.1.3 Fish stocks

Because so much of the bedrock is susceptible to rapid weathering, barrier falls that prevented access to anadromous fish were rare in the study stream, although there were exceptions in the Plutonic rocks of central and lower west coast Moresby Island. Streams in this area were generally steep with numerous waterfalls, and salmon production was typically low.

Of the streams examined, only the lower sections of large third-order streams (e.g., Bonanza, Government, Inskip, Riley, Sachs, or Windy Bay creeks) were used by pink salmon (Brown and Musgrave 1979; Marshall *et al.* 1978a, 1978b), while chum salmon and steelhead trout also use the numerous but smaller streams (e.g., Peel and Salmon rivers and Saltspring and Tarundl creeks, respectively). The most widely distributed species present were coho and Dolly Varden, which were present in virtually every stream reach sampled, and typically dominated the upper reaches and tributaries (e.g., Schomar Creek tributary) of larger streams, as well as the many small streams that flowed directly into the sea (e.g., Piper Creek, Macmillan Creek, South Bay Dump Creek). None of the streams sampled were used by sockeye or chinook salmon and only a few supported cutthroat trout.

TABLE 1. Summary of 1981 study reach characteristics. Values are means ±1SD; numbers in brackets are ranges

	Logged study reaches			Unlogged study reaches
	Pre-1966(old)	Post-1966(new)	All years	
		Mass wasting present		
No. reaches	9	5	14	2
Gradient (%)	5.5±2.7(2.6-9.7)	6.6±4.3(2.9-12.0)	5.9±3.2	8.0±2.7(6.1-9.9)
Stream length(km)	3.6±1.3(0.9-5.2)	4.7±3.3(1.1-10.0)	4.0±2.2	1.7±0.0(1.7-1.7)
Basic area(km²)	6.2±4.9(1.1-19.0)	7.1±6.3(1.6-17.8)	6.2±5.4	3.4±1.0(2.7-4.1)
% Basin logged	53±27(8-82)	62±18(36-77)	56±24	0
Avg. year logged	1952(1933-65)	1972(1968-78)	1958(1933-78)	NA
Avg. year upstream reaches logged	1973(1968-81)	1976(1970-81)	1974(1968-81)	NA
		Mass wasting absent		
No. reaches	14	4	18	3
Gradient (%)	3.4±2.9(0.8-12.4)	5.9±1.4(4.3-7.0)	3.8±2.9	4.7±3.7(2.7-9.2)
Stream length(km)	4.0±2.9(1.1-10.0)	2.6±2.8(0.9-6.7)	3.7±2.9	1.6±0.2(1.4-1.7)
Basin area(km²)	6.3±5.4(2.1-17.8)	3.7±4.9(0.5-11.0)	5.7±5.3	2.9±1.2(2.0-4.1)
% Basin logged	39±19(9-72)	31±8(25-37)	38±18	0
Avg. year logged	1942(1918-63)	1974(1970-78)	1947(1918-78)	NA
Avg. year upstream reaches logged	1973(1933-81)	1974(1970-82)	1973(1933-81)	NA
No. reaches with mass wasting upstream	7	2	9	2

TABLE 2. Summary of 1982 study reach characteristics. Values are means ±1SD; numbers in brackets are ranges

	Logged study reaches			Unlogged study reaches
	Pre-1966(old)	Post-1966(new)	All years	
		Mass wasting present		
No. reaches	9	3	12	1
Gradient(%)	3.4±2.1(0.9-7.1)	2.0±0.8(1.3-2.9)	3.1±1.9(0.9-7.1)	7.0
Stream length(km)	4.4±1.4(2.7-7.6)	9.8±5.1(4.1-13.9)	5.7±3.5(2.7-13.9)	1.7
Basin area(km²)	5.9±2.8(3.8-12.8)	27.2±21.0(5.4-47.4)	11.2±13.4(3.8-47.4)	1.6
% Basin logged	42±33(9-82)	14±3(12-17)	35±31(9-82)	0
Avg. year logged	1960(1946-65)	1976(1972-82)	1964(1946-82)	NA
Avg. year upstream reaches logged	1969(1961-82)	1976(1973-80)	1971(1961-82)	NA
		Mass wasting absent		
No. reaches	9	3	12	14
No. reaches with mass wasting upstream	4	1	5	4
Gradient(%)	2.1±1.0(0.8-3.8)	3.5±0.9(2.5-4.1)	2.5±1.2(0.8-4.1)	2.9±1.6(1.1-6.0)
Stream length(km)	4.8±2.5(1.1-10.0)	7.1±4.0(3.3-11.3)	5.4±2.9(1.1-11.3)	4.3±3.0(1.0-10.4)
Basin area(km²)	8.3±5.0(2.3-17.8)	14.6±12.7(4.0-28.7)	9.9±7.5(2.3-28.7)	8.1±7.0(1.6-21.2)
% Basin logged	36±21(10-72)	17±18(3-37)	32±21(3-72)	5±12(0-33)
Avg. year logged	1953(1936-67)	1974(1972-78)	1958(1936-78)	NA
Avg. year upstream reaches logged	1973(1964-82)	1980(1979-80)	1974(1964-82)	1979(1975-81)

TABLE 3. Summary of 1984 study stream characteristics

Stream	Stream length (km)	Basin area (km²)	% of Basin logged	Reach location[a] (m)	Reach gradient (%)	Year study reach logged[b]	Year upper reach logged	Mass wasting history
					Torrented study streams			
Lower Southbay	4.1	4.0	82	0-233	2.9	H 1960	H 1961-1980	Debris torrented 1978-1979; severe flood damage 1983
Macmillan	4.9	6.2	77	0-728	3.1	H 1946	H 1973-1983	Debris torrented 1978
Saltspring	3.6	6.3	13	0-493	3.5	H 1965	Unlogged	Upper reaches torrented 1978-1979; debris jam failures affecting study reach in 1981, 1982, and 1984
					Intermediate study streams			
Piper	4.8	4.2	10	0-835	2.2	A 1956	H 1976-1979	Severe flood damage 1983
Upper Southbay	4.1	4.0	82	233-590	4.0	H 1960	H 1961-1980	Debris torrented 1978-1979; LOD added 1982; severe flood damage 1983; re-torrented 1985
					Non-torrented study streams			
Schomar	3.4	6.6	36	0-668	2.1	H 1965-1966	H 1970-1976	Upper reaches torrented 1978; debris jam failed and affected study reach in 1984
Schomar Trib.	1.1	1.0	50 (est.)	10-235		H 1965-1966	H 1965-1966	No slides or debris torrents; road crossing 250 m above mouth collapsed in spring 1984
Tarundl	6.7	11.0	37	1640-2320	4.0	H 1972-1978	H 1978-1984	No recent slides or debris torrents; 5 m high debris jam at end of study reach

[a] Distance from stream mouth.

[b] H=high lead cable logging; A=A-frame logging.

3 STUDY DESIGN AND METHODOLOGY

The study was undertaken in two steps. In the first a "synoptic survey" of 44 streams was carried out from 1981 to 1982, modelled on the extensive post-treatment study design described by Hall and Knight (1981). This approach favours collecting a little detailed information on a large number of study streams rather than a lot on a few streams. Within FFIP a synoptic survey had several advantages, the most important of which was to permit a broad examination of stream habitat conditions under varying degrees of logging intensity, logging treatments, and mass wasting conditions. In 1983, the survey was followed by a more detailed examination of seven streams, which examined effects of mass wasting on juvenile fish and rearing habitats—a focus that could not be achieved using the synoptic survey approach.

3.1 Synoptic Habitat Survey

A fundamental limitation of any survey is the variability inherent within or between stream systems. Differences in basin morphometry, rainfall intensity, geology, and stream flow in 44 streams can have a strong influence on study results. To minimize the variability created by these factors, homogeneous stream reaches exhibiting uniform gradients, substrate, and valley shape characteristics were selected for study. Reaches were defined by measuring the channel profile, beginning from either the mouth or a point located 300-500 m downstream of some obvious mass wasting (e.g., the terminus of a debris torrent or landslide), and extending upstream to where the channel gradient exceeded 10-12% or where falls precluded further upstream movements of fish. The average length of stream profiled was 1100 m (±780, 1SD), ranging from 360 m in small Skaat Creek on south Moresby Island to 3880 m in Thurston Creek on Talunkwan Island.

A surveyor's tape or hip chain and a hand-held clinometer (Suunto PM-5) were used to measure stream length and channel gradient, respectively. Channel gradient measurements were taken at intervals of 20 m or less. During the traverse, stream reaches within a uniform gradient and logging history were defined and mass wasting features such as deposition and scour zones were marked on the profile. Other features such as large organic debris (LOD) jams, LOD steps, and side channels that may have had a major influence on the distribution of fish were also recorded. Valley width was measured every 100 m with a hip chain.

After homogeneous reaches were defined in each study stream, the amount of summer rearing habitat present was inventoried using two methods. In every case, measurements were recorded during a summer low flow period when the water was clear. Although seasonal differences in stage height undoubtedly accounted for some of the observed variability between streams, the variability was not considered a serious limitation. In 1981, a transect method was used whereby the habitat type present (pool, glide, riffle, side channel), maximum stream depth (cm), wetted width and rooted width (channel width from rooted vegetation to rooted vegetation, 0.1 m), and presence or absence of stable LOD were recorded at 20 m intervals to a maximum of 15 intervals per reach.

To determine the proportion of total stream area occupied by each habitat type (pool, glide, or riffle), the average wetted width recorded for each was multiplied by the proportion of transects recorded with that habitat. The result was then divided by the sum of the products for pools, glides, and riffles combined.

A slightly different approach was used in 1982, where instead of noting the habitat present at 20 m intervals, each pool, riffle, or glide in the study reach was described separately over a maximum of 500 m of stream. The same information collected in 1981 at individual transects was repeated for each habitat feature in 1982, with additional information collected on the area of each habitat feature, the area of stable LOD (within the wetted perimeter of the channel and within 1.0 m of the water surface), and the area of stable undercut bank (overhanging banks held together by roots within 0.5 m of the water surface).

These areas were measured directly with a surveyor's tape and metre stick or, in the case of very complex configurations of LOD, estimated visually on the basis of percent coverage in each feature. For the latter method, the percent coverage estimate was compared to the area measured to estimate areal coverage. In 1981 and 1982, pools were defined as those features with the greatest depth, a low gradient, and a placid surface; riffles were shallow, steep gradient features, usually with surface turbulence. Glides were features with characteristics midway between those of pools and riffles, with typically even, laminar flows, and little or no cover in the form of water depth and surface turbulence.

3.2 Detailed Habitat Survey

Each pool in the seven streams selected for study in 1983/1984 was further described according to Bisson *et al.* (1982) as a secondary channel pool, backwater pool, trench pool, plunge pool, lateral scour pool, or dammed pool. Underscour pools formed by instream or overhanging debris that deflected flows downward and underneath were also noted, and riffles were sub-categorized as riffles, cascades, or rapids. The material or feature (e.g. streambanks, LOD, boulders, bedrock) controlling the nature of each habitat unit was also recorded, along with the length (both sides) of stable rooted banks.

Fish cover, in the form of upturned rootwads and other LOD, small organic debris (SOD), undercut banks, overhanging vegetation, boulders, surface turbulence, and deep water, was also identified and recorded separately in planview to the nearest 0.1 m^2. Stable undercut banks were measured with the same technique described in Section 3.1. SOD included any stems, limbs, or pieces of wood that touched the water surface and were less than approximately 0.03 m^3 (1 ft^3) in volume. The length and diameter of each piece of LOD lying within the wetted perimeter of the channel and 1 m of the water surface were measured to the nearest 0.1 m; the orientation of each LOD was recorded as either perpendicular (±22.5°), diagonal, or parallel to the main direction of stream flow. The position of each LOD piece relative to the water surface was recorded as over, under, or alongside.

Only in pools was deep water considered to be cover, and then only in that portion of the pool deeper than the greatest depth recorded in adjacent riffles. Boulder cover was estimated by measuring the amount of quiet water present behind a subsample of average-sized boulders in the reach, and then counting the number of boulders present in each feature, with appropriate allowances for bedrock or unusally large boulders. Surface turbulence, measured directly in pools, was estimated in riffles by taking the average area covered by sites with frothing or bubbling water and multiplying it by the number of frothy or bubbly spots present. Vegetative cover was defined as the amount of stream area overhung — to within 2 m of the water surface — by vegetation. The amount of cover available for juvenile fish during low flow periods in torrented, non-torrented, and intermediate type stream reaches was further divided into "summer" and "winter" cover. Summer cover included all of the cover characteristics (rootwads, LOD, SOD, overhanging vegetation, undercut banks, boulders, surface turbulence, deep water) measured in each habitat type (pools, glides, or riffles); winter cover included only some of the cover characteristics (rootwads, LOD, undercut banks, boulders, deep water) measured only in LOD controlled pools. Clearly not all of the cover characteristics were independent of each other nor equally important to fish. For purposes of this study, however, they were treated the same so that they could be added together to provide a measure of "total" cover.

3.3 Habitat Analysis

Differences between the mean values of most parameters in mass and non-mass wasted (or logged and unlogged) streams were compared with a two-tailed t-test (Steel and Torrie 1960), or for enumerative data, a Chi-square test. When other variables such as stream gradient were included as covariates, regression equations were computed and the slopes and adjusted means of significantly correlated relationships compared using t-tests and F-tests. Habitat and cover

diversity were compared with a diversity index, d (Shannon and Weaver 1949), computed as follows (from Lloyd *et al.* 1968):

$$d = \frac{C}{A}(A \log A - a_i \log a_i)$$

where $C = 3.32193$

A = total habitat or cover area

a_i = total wetted area of the i^{th} habitat or cover type.

4 RESULTS

4.1 Synoptic Survey Stream Habitat Characteristics

This section focuses on the synoptic survey portion of the fish habitat studies and describes the relationships between mass wasting, forest harvesting, and the amount of juvenile fish habitat present during the summer low flow periods of 1981 and 1982. Because sampling methods differed for 1981 and 1982, data for the 2 years are treated separately. Site-specific information on the logging and mass wasting histories of each study reach are provided in Tables A1 and A2, while data on habitat characteristics are provided in Tables A3 to A7.

4.1.1 Productive stream length affected by debris torrents

A productive stream channel was defined in this study as one having a gradient less than 7.0%. This coincides with the maximum average stream gradient recorded for habitat used by juvenile coho, in those streams on the Islands that do not have barriers to adult fish.[4] The value, therefore, represents the approximate upstream limit of habitat available to anadromous fish.

In logged areas, debris torrents affected an average of 616 m of productive stream channel, or 66% of the stream area normally available to anadromous fish, compared to only 31% in unlogged areas (Table 4). Because of high variability in the amount of habitat affected in logged areas and the small sample size for unlogged stream (N=3), the differences in the length of anadromous habitat affected were not statistically significant ($0.05<P<0.1$). However, at least one debris jam (Saltspring Creek) has failed twice since 1982, once during the 1982/1983 winter period and once during the 1983/1984 period, causing extensive damage throughout the lower stream sections. Previously, only 26% of the anadromous habitat available was affected, but in 1984, 100% was affected. Thus, by 1984 the average amount of anadromous fish habitat in logged areas directly affected by torrenting was 72%, in contrast to 31% in unlogged areas ($P<0.05$). Four (20%) of the 20 debris torrents examined during this study eventually moved into the sea, while 16 (80%) stopped along the stream channel, usually as immense debris jams extending from valley wall to valley wall. The average stream gradient recorded at the toe of both logged and unlogged area debris torrents was 3.5 ± 1.5% (±1 SD, N=15, range 1.2-6.2%), while the average height of the jams was 6.4 ± 3.4 m (N=8, range 2.0-13.0 m).

All of the stream reaches directly affected by debris torrents were first- and second-order perennial streams (Strahler 1957). All contained resident Dolly Varden char populations, and in some cases isolated resident cutthroat or rainbow trout populations. Where there were no barriers to anadromous fish, coho were invariably present also, and sometimes steelhead trout. Chum salmon were usually only directly affected when the entire length of some of the smaller streams used by chum were torrented (e.g., Macmillan Creek, Saltspring Creek, Shelley Creek, Southbay Dump Creek). Pink salmon, unlike chum or coho salmon, generally only spawned in the third-order stream reaches sampled (e.g., lower Sachs Creek, Windy Bay Creek, Government Creek) and were thus only directly affected by debris torrents when they entered streams from hillsides immediately adjacent to low gradient reaches (e.g., Bonanza Creek).

4.1.2 1982 pool/riffle relationships

The distribution of pool, glide, and riffle areas in the 1982 study reaches was compared in relation to mass wasting and logging (Table 5). The summary is based on all of the study reaches sampled in 1982, except Bonanza, Hangover, and Riley creeks. The latter three streams, all large second- and third-order streams located in Rennell Sound, were excluded from the analysis because their riffle areas were substantially smaller (10.3%, $P<0.05$) than

[4] Tripp and Poulin (1986b).

TABLE 4. Distance travelled by debris torrents in first- and second-order stream sections with gradients less than 7%

Stream	Stream Length (m) Under 7%	Torrented stream Length (m) Under 7%	Torrented stream Length (%) Under 7%
Logged			
Clew	1120	560	50
Little Goose Trib.	460	180	39
Macmillan	900	900	100
Mosquito Lake Trib	1500	760	51
Powrivco Bay	430	430	100
Saltspring	460	120	26
Sandy Trib.	440	220	50
Southbay Dump	700	700	100
Talunkwan	1080	720	67
Thurston	3600	1700	47
Thurston Harbour	380	280	74
Two Torrent	920	830	90
Unlogged			
Government Trib.	300	160	53
Phantom Trib.	1200	285	24
Windy Bay Trib.	780	120	15
Logged Mean ± 1 SD (Range)	999±891 (380-3600)	616±435 (120-1700)	66±26 (26-100)
Unlogged Mean ± 1 SD (Range)	760±450 (300-1200)	188±86 (120-285)	31±20 (15-53)

those in all other streams (49.5%). Because gradients in these streams were not lower, some atypical conditions were indicated, as discussed in Section 4.1.6 and Section 4.1.7.

Stream reaches with mass wasting had significantly less pool area ($P<0.05$), and more riffle area, compared to stream reaches without mass wasting. In mass wasted streams, including both logged and unlogged streams, pool area declined from 35% of total wetted surface area to 15%, an overall net decrease of about 57%. Riffle area showed exactly the opposite pattern — an overall net increase of 57%, from 42% of the wetted surface area in non-mass wasted streams to 66% in mass wasted streams. There were no differences in the amounts of pool, glide, or riffle area present between logged and unlogged streams with no mass wasting ($P>0.05$) (Table 5). Though the data for recently logged streams are scarce, this indicates that logging by itself (i.e., mass wasting aside) had little or no effect on pool/riffle ratios among the 1982 study reaches.

Stream gradient could have had an effect on pool area because mass wasted stream reaches also had, on average, higher gradients than non-mass wasted reaches (3.4% vs 2.7%, respectively). Percent pool and riffle surface area were therefore regressed against gradient for mass and non-mass wasted streams, using only first- and second-order streams of comparable length (less than 6.0 km) to determine more precisely the relationship between

TABLE 5. Distribution of pool, glide, and riffle surface areas (% of wetted area ±1 SD) in relation to mass wasting and logging in 1982 study reaches. Square brackets are values compared and found to be significantly different

Condition	Unlogged reaches	Logged reaches			All reaches
		Old	New	All	
Pools					
Mass wasting	5.0(N=1)	[15.2± 8.8(N=9)	23.0(N=1)	[16.0± 8.6(N=10)	[15.0± 8.8(N=11)
No mass wasting	32.7±16.1(N=14)	[42.8±11.8(N=9)	12.0± 5.7(N=2)	[37.2±16.3(N=11)	[34.7±16.1(N=25)
Glides					
Mass wasting	9.0(N=1)	18.1± 8.4(N=9)	41.0(N=1)	20.4±10.8(N=10)	19.4±10.8(N=11)
No mass wasting	24.7±13.5(N=14)	21.6±11.3(N=9)	18.0± 5.7(N=2)	20.9±10.4(N=11)	23.0±12.7(N=25)
Riffles					
Mass wasting	86.0(N=1)	[66.9±15.7(N=9)	36.0(N=1)	[63.8±17.7(N=10)	[65.6±17.9(N=11)
No mass wasting	42.6±19.9(N=14)	[35.7± 8.0(N=9)	70.0±11.3(N=2)	[41.9±16.0(N=11)	[42.3±17.9(N=25)

[a] $P<0.001$.

water surface area, gradient, and mass wasting (Fig. 2). Both the slopes and intercepts of the pool area gradient relationships differed significantly ($P<0.05$) (Fig. 2), indicating that mass wasting reduces the amount of pool habitat present in directly affected streams. This was particularly true in low gradient reaches and less so in high gradient reaches. Although significant differences could not be demonstrated for the percent riffle area gradient relationships, the pattern remained the same: more riffle area in low gradient sections of mass wasted streams, but similar riffle area in high gradient sections.

Accordingly, percent pool area in mass wasted streams declined from 43 to 24% at a gradient of 1%, and from 13 to 7% at a gradient of 7%. Overall, there appears to be approximately a 45% reduction in the amount of pool habitat available in reaches directly affected by mass wasting, regardless of stream gradient. Differences in the average gradient of mass and non-mass wasted study reaches probably accounts for only 12% of the difference between the amount of pool habitat present.

4.1.3 1981 pool/riffle relationships

The 1981 study reaches directly affected by mass wasting also had less pool and glide habitat (and more riffle habitat) than non-mass wasted reaches. The data were, however, highly variable and the differences were not statistically significant (Table 6). Much of the variability occurred among the non-mass wasted reaches, where the type of logging conducted in three streams resulted in their being channelized or destabilized to a point where conditions closely resembled the effects of a debris torrent. All three streams (Richardson, Beljay, and Takelly creeks) were located in Atli Inlet on Lyell Island and had been logged between 1918 and 1935 with A-frame and/or skidder logging techniques. In two streams (Takelly and Beljay creek) there was virtually no LOD left and the stream flowed a more or less straight course down what once appeared to be a main skid trail. In the third creek (Richardson Creek), it appears that a combination of little debris and an excess of unstable, highly mobile sediment deposits has contributed to an unusually high degree of dewatering at low flows.

When the above three streams, representing five out of a total of 36 reaches, were deleted from the analysis, the 1981 pool/riffle data showed the same patterns and approximate values described for 1982, despite the differences in sampling methods in the 2

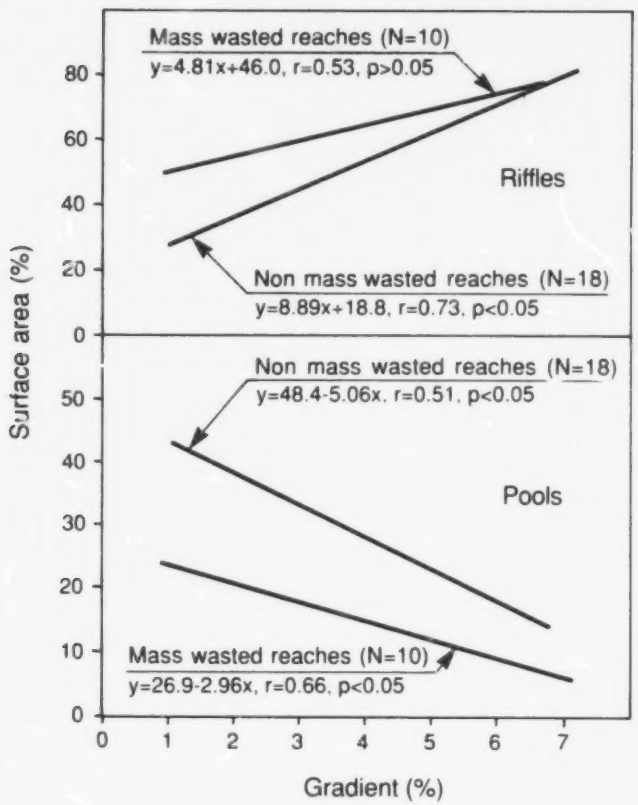

FIGURE 2. Relationships between percent pool-riffle area and stream gradient in mass and non-mass wasted streams sampled in 1982.

years. As in 1982, mean percent pool area in logged streams affected by mass wasting showed a significant decline ($P<0.05$), from 34 to 21% of the total stream area (Table 6), for an overall net decline of 38%. Similarly, percent mean riffle area increased from 45 to 66% ($P<0.05$), for an overall net increase of 47%.

The relationships between pool/riffle areas and stream gradient in mass and non-mass wasted streams in 1981 (Fig. 3) were also essentially the same as those for the 1982 streams. Although data for mass wasted streams in 1981 were more variable than in 1982, in both years there was a considerable reduction (up to 44-64%) in pool area in low gradient sections of mass wasted streams, and a corresponding increase in riffle area. Differences in pool/riffle areas also declined in progressively steeper stream sections, eventually disappearing at gradients exceeding 7%.

4.1.4 Pool depth

Mass wasting appears to reduce not only the amount of pool area available to fish in directly affected reaches, but also net pool depth (here defined as the difference between the mean maximum pool depth recorded in each study reach and the mean maximum riffle depth.) Net pool depth declined significantly from 0.50 m in non-mass wasted streams (logged and unlogged streams combined) to 0.35 m in mass wasted streams, or approximately 31% ($P<0.05$) (Table 7). Slightly greater reductions are apparent when just logged streams are considered, from 0.52 to 0.35 m (a 33% decline) in old and new logged reaches combined, and from 0.51 to 0.30 m (a 41% decline) in old logged reaches alone. For stream reaches

TABLE 6. Distribution of pool, glide, and riffle surface areas (% of wetted area ±1 SD) in relation to mass wasting and logging in 1981 study reaches. Square brackets are values compared and found to be significantly different

Condition	Unlogged reaches	Logged reaches: Old	Logged reaches: New	Logged reaches: All	Reaches
Pools					
Mass wasting	27.0±12.7(N=2)	[18.1±12.0(N=8)	22.4± 6.9(N=5)	[19.8±10.2(N=13)	[20.7±10.4(N=15)
No mass wasting	25.7±18.5(N=3)	a [28.9±16.5(N=14)	32.5±18.0(N=4)	a [29.7±16.4(N=18)	a [29.1±16.3(N=21)
No mass wasting -Takelly, Beljay, Richardson	25.7±18.5(N=3)	[37.9±12.3(N=9)	32.5±18.0(N=4)	[35.2±13.7(N=13)	[34.3±14.7(N=16)
Glides					
Mass wasting	8.0± 7.1(N=2)	13.1± 7.8(N=8)	16.0±14.8(N=5)	14.2±10.6(N=13)	13.4±10.2(N=15)
No mass wasting	10.7± 5.1(N=3)	16.7±14.1(N=14)	22.0±15.1(N=4)	17.9±14.1(N=18)	16.9±13.3(N=21)
No mass wasting -Takelly, Beljay, Richardson	10.7±5.1(N=3)	23.0±13.5(N=9)	22.0±15.1(N=4)	22.7±13.4(N=13)	20.4±13.0(N=16)
Riffles					
Mass wasting	65 ±19.8(N=2)	[68.6±11.4(N=8)	61.4±15.9(N=5)	[65.8±13.2(N=13)	[65.7±13.3(N=15)
No mass wasting	63.7±17.6(N=3)	a [53.5±25.3(N=14)	45.5± 7.6(N=4)	a [51.7±22.6(N=18)	a [53.4±22.0(N=21)
No mass wasting -Takelly, Beljay, Richardson	63.7±17.6(N=3)	[37.7±14.0(N=9)	45.5± 7.6(N=4)	[40.1±12.6(N=13)	[44.5±16.1(N=16)

[a] $P<0.001$.

TABLE 7. Mean net maximum pool depth (m; ±1 SD) in mass and non-mass wasted stream reaches with different logging histories, 1982 study reaches

Mass wasting Condition	Unlogged reaches	Logged reaches: Old	Logged reaches: New	Logged reaches: All	All reaches
Mass wasting	No data	0.30±0.17(N=9)	0.43±0.22(N=4)	0.35±0.18(N=13)	0.35±0.18(N=13)
No mass wasting	0.50±0.23(N=15)	0.51±0.15(N=9)	0.60±0.25(N=2)	0.52±0.16(N=11)	0.50±0.19(N=26)
Net decrease	No data	0.21[a]	0.17	0.17[a]	0.15[a]
% Decrease	No data	40.7[a]	28.3	30.8[a]	30.0[a]

[a] $P<0.01$.

with no mass wasting, there were no differences between either logged and unlogged streams or old and new logged streams (Table 7). Neither were there any apparent differences between stream reaches with mass wasting upstream (net pool depth 0.53 ±0.22 m, N=12) and those with no mass wasting (net pool depth 0.51 ±0.20 m, N=14).

Net pool depth was negatively correlated ($P<0.05$) with stream gradient in both mass and non-mass wasted stream reaches (Fig. 4), however, no significant differences could be demonstrated between the slopes or intercepts of the two relationships. This indicates that the sample points for both mass and non-mass wasted stream reaches originated from the same population, and that differences in stream gradient account for at least a portion of the difference observed in pool depth. The common regression line relating gradient to pool depth in mass and non-mass wasted streams combined was:

Net Pool Depth (cm) = 65.7 - 49.5 log Stream Gradient (%)

(N=39, r=-0.593, $P<0.01$, Gradient Range 0.8 - 7.1%)

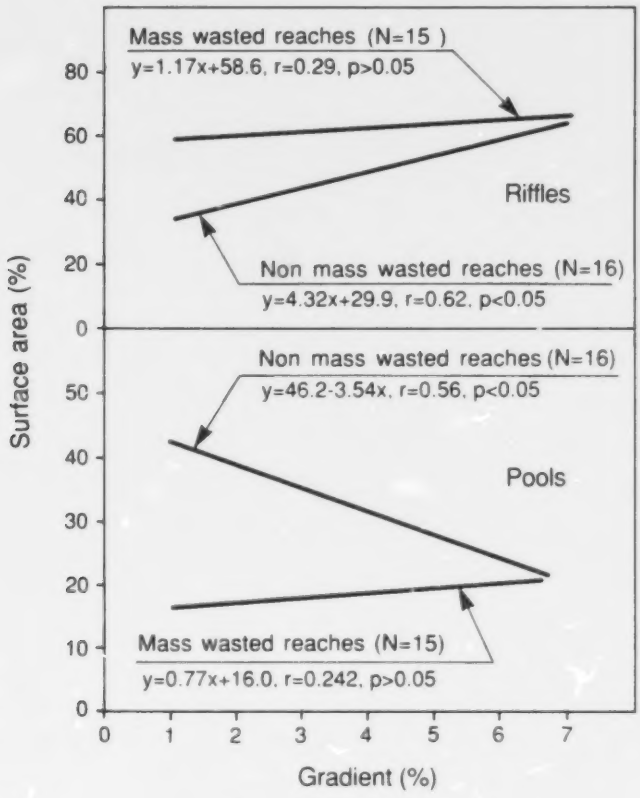

FIGURE 3. Relationships between percent pool-riffle area and stream gradient in mass and non-mass wasted streams sampled in 1981.

In Table 8, a comparison of the net pool depths predicted in Figure 4 for mass and non-mass wasted streams suggests that differences in stream gradient can account for 5-10 cm of the average reduction observed in net pool depth. Since this is only a third to a half of the total reduction observed, presumably the rest of the reduction is due to mass wasting, either through infilling or changes in the type of pools present. If so, then the overall reduction in pool depth caused by mass wasting is about 10-13 cm, or approximately 20-24% of the net maximum pool depth in non-mass wasted streams with comparable logging histories.

4.1.5 Undercut banks

Logging by itself (old and recent combined) reduced the amount of undercut bank area present in streams on the Queen Charlotte Islands by 56.3%, from 3.0% of the total wetted surface area in non-mass wasted unlogged streams to 1.3% in non-mass wasted logged streams ($P<0.05$) (Table 9). While old logged reaches showed slightly higher declines (59.5%) than more recently logged reaches (46.4%), the data for the latter were based on only three samples and significant differences could not be demonstrated.

Mass wasting further reduced the amount of undercut bank area present in logged areas by an additional 19.7%, for an overall reduction of 76.0% ($P<0.05$). Although only one mass wasted stream was sampled in an unlogged area, the amount of undercut bank area lost (73.7%) was almost the same as that lost in mass wasted logged streams. This suggests that mass wasting alone probably reduces undercut bank area as much as logging and mass wasting together.

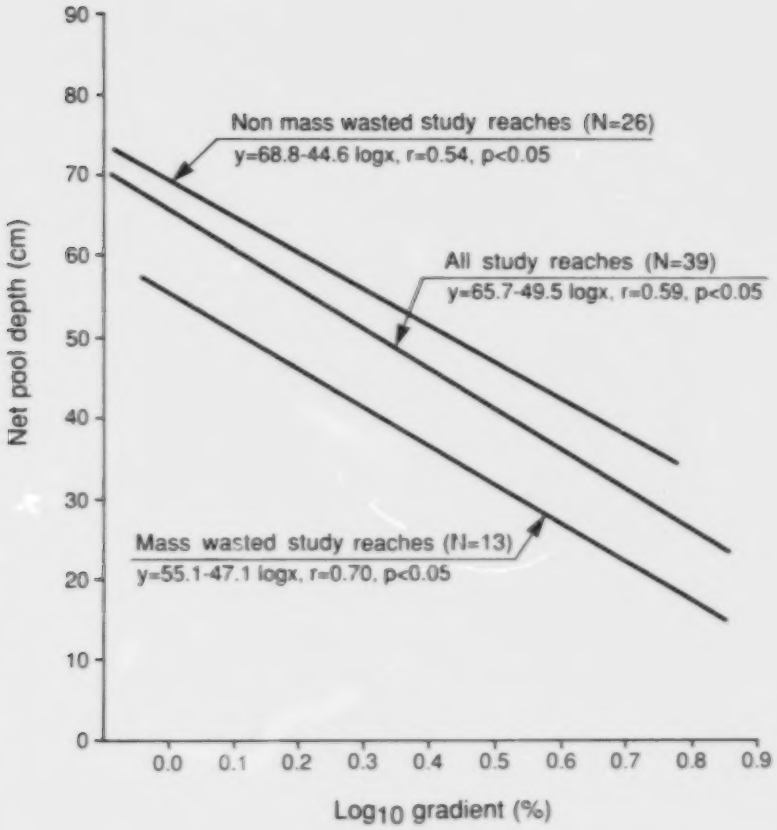

FIGURE 4. Stream gradient/net pool depth relationships in mass and non-mass wasted stream reaches.

4.1.6 Large organic debris cover

Among non-mass wasted streams, logging alone appeared to reduce LOD cover area by 26.5% (Table 10), with the greatest reduction occurring in reaches logged prior to 1966 (33.6%) and a relatively small reduction occurring in those logged after 1966 (5.3%). None of the differences were significant owing to the small sample size for recently logged streams (N=3) and the high variability recorded in unlogged streams. Mass wasting in logged streams further reduced the LOD area by an additional 31% ($P<0.05$), for an overall reduction of 57.5% from logging and mass wasting combined ($P<0.05$). Again, the declines were greatest in old logged streams (69%) and least in more recently logged streams. The latter, however, included Bonanza and Riley creeks, both of which, as noted earlier, were low gradient depositional zones. As Shelley Creek shows, when high gradient sections of recently logged streams are torrented, the reductions in LOD cover are similar to old logged streams.

There was a clear relationship between the amount of pool area present in each study reach and the amount of stream area covered by LOD (Fig.5) ($R=0.67, P<0.05$). This also indicates that the decline in pool area described earlier for mass wasted streams is largely the result of declines in LOD cover. Where debris cover was high in mass wasted stream reaches (e.g., Bonanza and Riley creeks) so was pool area, the one exception being Mosquito Creek. Other streams with high amounts of LOD but relatively low pool areas (the "A" stream group in Figure 5) tended to be unlogged streams with high banks or a narrow V-shaped valley. In these streams, much of the LOD present was composed of very large trees suspended just

TABLE 8. Estimated net pool depth (cm) lost because of differences in stream gradient and mass wasting, 1982 study reaches

	Logged and unlogged streams	Old logged streams	Old and new logged streams
Net pool depth predicted by stream gradient			
-Mass wasted streams	39.4	39.4	41.4
-Non-mass wasted streams	44.3	49.7	46.0
Proportion of net pool depth losses attributed to differences in stream gradient	4.9	10.3	4.6
Actual differences observed between mass and non-mass wasted streams	15.1	20.6	17.3
Proportion of net pool depth losses attributed to mass wasting	10.2	10.3	12.7
Estimated % decline from mass wasting	20.3	20.3	24.3

TABLE 9. Stable undercut bank area (% of wetted surface area ±1 SD) in relation to mass wasting and logging in the 1982 study reaches

Mass wasting condition	Unlogged reaches	Logged reaches			All reaches
		Old	New	All	
Mass wasting	0.08(N=1)	0.67±1.01(N=9)	0.90±0.36(N=3)	0.73±0.88(N=12)	0.73±0.84(N=13)
No mass wasting	3.04±2.04(N=15)	1.23±0.87(N=9)	1.63±1.37(N=3)	1.33±0.96(N=12)	2.28±1.84(N=27)
Net decrease from logging (%)		1.81(59.5)[a]	1.41(46.4)	1.71(56.3)[a]	
Additional decrease from mass wasting (%)	2.24(73.7)	0.56(18.4)	0.73(24.0)	0.60(19.7)	
Total decrease from logging and mass wasting (%)		2.37(78.0)[b]	2.14(70.4)	2.31(76.0)[b]	2.31(76.0)[c]

[a]=P<0.05.
[b]=P<0.01.
[c]=P<0.001.

over the stream channel. Although recorded as cover, in fact a substantial portion of the LOD present probably had little influence on channel morphology and pool development.

Both LOD cover (percent of wetted surface area) and stream gradient (%) were significantly correlated with percent pool area (P<0.01) according to equations (1) and (2) below, but not with each other (r=-0.20, N=40). The best multiple linear regression relating pool area (percent of stream area) to LOD cover (percent of stream area) and stream gradient (%) is given in equation (3):

Pool Area = 2.49 LOD Area + 12.324
(r=0.67, LOD Area Range 0.3-26.5%, N=40) (1)

Pool Area = 48.93 - 5.59 Gradient
(r=-0.48, Gradient Range 0.8 - 7.0%, N=40) (2)

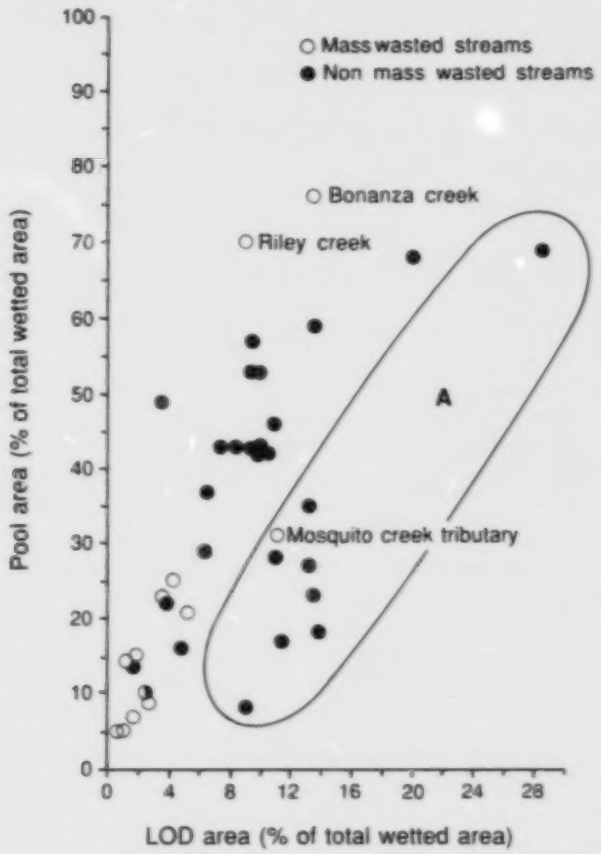

FIGURE 5. LOD/pool area relationship for mass and non-mass wasted Study Streams on the Queen Charlotte Islands.

$$\text{Pool Area} = 38.43 + 2.22\ \text{LOD Area} - 4.25\ \text{Gradient (\%)} \quad (3)$$

The R value for equation (3) above was 0.753 ($P<0.05$), which suggests that LOD cover (expressed as a percent of the total stream area) and stream gradient can account for approximately 57% of the total variation in mean pool area in mass and non-mass wasted streams. Comparison of the partial regression coefficients for LOD area ($b = 0.596$) and gradient ($b = 0.359$) further indicates that LOD area is 1.7 times more useful than gradient in estimating pool area.

4.1.7 Stream width and dewatering

An examination of the data on wetted stream width, rooted stream width, and rooted/wetted stream width ratios in 1981 (Table 11) and 1982 (Table 12) did not reveal any significant patterns in relation to logging that could not be attributed to simple differences in stream width. Mass wasting, on the other hand, significantly increased the average rooted width of logged and unlogged streams sampled in 1981 and 1982 by 8.5 and 9.4 m, respectively—an increase of 48-77% ($P<0.05$). Likewise, the ratios of rooted to wetted stream width were 103% (1982 streams) to 129% (1981 streams) higher in mass wasted streams compared to non-mass wasted streams ($P<0.05$).

TABLE 10. Large organic debris cover (% of wetted surface area ±1 SD) in relation to logging and mass wasting in the 1982 study reaches

Mass wasting condition	Unlogged reaches	Logged reaches			All reaches
		Old	New	All	
Mass wasting	0.3(N=1)	3.5±3.2(N=9)	8.6±5.0(N=3)	4.8±4.2(N=12)	4.4±4.2(N=13)
No mass wasting	11.3±5.5(N=15)	7.5±2.6(N=9)	10.7±6.7(N=3)	8.3±3.9(N=12)	10.0±5.0(N=27)
Net difference from Logging (%)		-3.8(33.6)	-0.6(5.3)	-3.0(26.5)	
Additional difference from mass wasting (%)	-11.0(97.3)	-4.0(35.4)[a]	-2.1(18.6)	-3.5(31.0)[a]	
Total difference from logging and mass wasting (%)		-7.8(69.0)[c]	-2.7(23.9)	-6.5(57.5)[b]	-6.9(61.1)[b]

[a]=P<0.05.
[b]=P<0.01.
[c]=P<0.001.

TABLE 11. Summary of mean wetted width (m), rooted width (m) and rooted/wetted width ratios (±1 SD) in relation to logging and mass wasting in the 1981 study streams. Square brackets are values compared and found to be significantly different

Mass wasting condition	Unlogged reaches	Logged reaches			All reaches
		Old	New	All	
		Wetted width			
Mass wasting	2.1±0.8(N=2)	3.1±0.6(N=8)	2.6±0.4(N=4)	3.0±0.6(N=12)	2.8±0.7(N=14)
No mass wasting	2.8±0.9(N=3)	4.1±1.4(N=9)	3.2±1.7(N=4)	3.8±1.5(N=13)	3.6±1.4(N=16)
		Rooted width			
Mass wasting	26.1±8.4(N=2) [a]	20.2±6.8(N=8) [a]	14.9±5.4(N=4)	18.4±6.7(N=12) [b]	19.5±7.1(N=14) [c]
No mass wasting	9.9±2.0(N=3) [a]	12.5±6.4(N=9) [a]	8.3±4.0(N=4)	11.2±6.0(N=13) [b]	11.0±5.4(N=16) [c]
		Rooted/wetted width ratio			
Mass wasting	12.2±0.5(N=2) [b]	6.5±1.5(N=8) [c]	5.9±2.5(N=4)	6.3±1.8(N=12) [c]	7.1±2.7(N=14) [c]
No mass wasting	3.7±0.8(N=3) [b]	3.0±0.9(N=9) [c]	2.8±0.8(N=4)	3.0±0.9(N=13) [c]	3.1±0.9(N=16) [c]

[a]=P<0.05.
[b]=P<0.01.
[c]=P<0.001.

The ratio of rooted to wetted stream width increased in mass wasted streams for two reasons: 1) because streambanks were gouged out, and 2) because excess sediments increased the amount of subsurface flow. Dewatering per se was not measured on a routine basis; however, to demonstrate the potential magnitude of the problem, it was examined in one stream during the study. On a tributary to Mosquito Creek on the Pallant River system, water percolating through gravel during what was considered a very dry summer in 1982 resulted in an 81% reduction in stream area, most of it lost in side channels and riffles (Table 13). By comparison, two other streams (one a debris torrented tributary to Mosquito Lake, the other a logged but otherwise unaffected stream, Tarundl Creek) lost 37 and 34% of their

TABLE 12. Summary of mean wetted width (m), rooted width (m), and rooted/wetted width ratios (±1 SD) in relation to logging and mass wasting in the 1982 study reaches. Square brackets are values compared and found to be significantly different

Mass wasting condition	Unlogged reaches	Logged reaches			All reaches
		Old	New	All	
Wetted width					
Mass wasting	2.9(N=1)	4.1±2.0(N=9)	6.8±3.0(N=3)	4.8±2.4(N=12)	4.7±2.4(N=13)
No mass wasting	6.9±5.1(N=15)	6.7±4.0(N=9)	5.8±1.1(N=3)	6.5±3.5(N=12)	6.7±4.4(N=27)
Rooted width					
Mass wasting	10.4(N=1)	30.9±11.1(N=9)	29.6±12.8(N=3)	30.6±17.2(N=12) [a]	29.0±17.4(N=13) [a]
No mass wasting	21.7±13.1(N=15)	16.8±7.3(N=9)	17.3±10.4(N=3)	16.9±7.6(N=12) [a]	19.6±11.1(N=27) [a]
Rooted/wetted width ratio					
Mass wasting	3.6(N=1)	8.0±4.1(N=9) [a]	4.5±1.1(N=3)	7.1±3.9(N=12) [b]	6.9±3.8(N=13) [c]
No mass wasting	3.9±2.3(N=15)	2.8±0.5(N=9) [a]	2.8±1.2(N=3)	2.8±0.7(N=12) [b]	3.4±1.8(N=27) [c]

[a] = $p < 0.05$.
[b] = $p < 0.01$.
[c] = $p < 0.001$.

TABLE 13. Seasonal variation in wetted surface area and stream length in Mosquito Creek tributary, Mosquito Lake tributary, and Tarundl Creek, June 6 - September 29, 1982

Stream	Date	Stream reach length(m)	Wetted stream length(m)	Water surface area (m^2)			% Surface area lost
				Main channel	Side channel	Total	
Mosquito Ck tributary	July 28	600	600	2951	1257	4208	
							49.8
	Aug 23	600	531	1853	259	2112	
							81.0
	Sept 28	600	293	711	87	798	
Mosquito Lk tributary	June 16	200	200	458	26	484	
							0.0
	Aug 23	200	200	495	0	495	
							36.6
	Sept 29	200	188	307	0	307	
Tarundl Ck	June 6	450	450	3033	249	3282	
							6.8
	Aug 27	450	450	2901	157	3058	
							34.1
	Sept 29	450	450	2003	160	2163	

wetted area, respectively, during approximately the same period. More significantly, 50% of the stream length studied on the Mosquito Creek tributary dried up, compared to only 6% of the Mosquito Lake tributary and none of Tarundl Creek.

Other areas potentially affected by stream dewatering included both logged (Bonanza and Riley creeks) and unlogged (Hangover Creek) streams in the Rennell Sound area. In these streams, riffles accounted for only 8-11% of the total surface area during low flow periods, primarily because of the many isolated pools and side glides formed by receding water levels.

Unlike most other stream reaches affected by mass wasting, almost all of the pool habitat in the study reaches of Bonanza, Riley, and Hangover creeks were formed by the stream spilling over or under LOD positioned across the stream (Hogan 1986). Generally speaking, pools formed by scouring around LOD tended to be shorter and steeper than pools formed without LOD, and were therefore less sensitive to dewatering.

4.2 Detailed Survey Streams

As previously indicated, one of the main reasons for conducting another habitat survey in 1984 was to provide more specific information on the nature of the habitat in mass and non-mass wasted streams. Whereas the synoptic survey concentrated only on general characteristics such as pool/riffle ratios, stream depth and width, and total LOD cover in a large number of streams, the detailed studies focused on the specific types of pools present, the scour agents responsible for the formation of pools, LOD characteristics, and the relative importance of the various types of fish cover present.

4.2.1 Pool diversity and overwinter habitat

Like the synoptic survey results, the data collected from the detailed study reaches (Table 14) indicated that torrented stream reaches have significantly more riffle area (%) and less glide area than non-torrented reaches ($P<0.05$). They may also have less pool area (23.9% vs 36.5%), primarily because of the loss of plunge pools and dammed pools. The amount of backwater, underscour, trench, and side-pool areas available in torrented reaches was, on average, only slightly lower than the amounts available in non-torrented reaches; the amount of lateral scour pool area was slightly higher. Only plunge pool areas were significantly different ($P<0.05$).

The total number of pool types present in each stream type ranged from an average 4.3 (range 3-6) per study reach in non-torrented streams to 2.8 (range 1-3) in torrented streams and the differences were significant ($P<0.05$)(Table 14). While every study reach in the non-torrented streams had at least three different kinds of pools — usually lateral scour, plunge, and backwater pools, sometimes only lateral scour pools were present in torrented streams. Most non-torrented streams supported a complex assemblage of lateral scour, plunge, dammed, backwater, and bedrock controlled trench pools. Torrented streams were typically characterized by lateral scour and cascade-like (boulder controlled) trench pools.

There were no significant differences between the amount of pool area formed as a result of scouring around LOD in torrented (13.7 - 11.4%) and non-torrented (25.6 - 18.0%) stream reaches, although variation was high (Table 15). There were, however, significant differences in the various scouring agents in each stream type.

Approximately 73% of the pools enumerated in non-torrented streams were formed by scouring around LOD, while only 40% of the pools in torrented streams were formed this way (Chi-square, $P<0.05$). Boulders, in contrast, accounted for 46% of the pools scoured out in torrented streams, but only 13% in non-torrented streams. In both stream types, streambanks and bedrock outcropping accounted for the formation of 13-14% of the pools. Clearly, the single most important difference between the factors governing pool formation in torrented and non-torrented streams was the shift from LOD to boulders as the principal scouring agent in torrented streams.

The habitat diversity index (d) was used here to measure the "evenness" of the contribution by each habitat category (i.e., riffles, glides, plunge pools, trench pools etc.), to total stream area. When the stream habitat is unevenly divided among a few categories, a relatively low index results; when the habitat is evenly divided among many categories, relatively high values result.

Comparison of diversity indices indicated that the overall habitat diversity of torrented study reaches ($d = 1.48$) was significantly lower than non-torrented reaches ($d = 2.30$,

TABLE 14. Comparison of pool, riffle, and glide habitats in torrented and non-torrented stream reaches. Mean values with the same superscripts were significantly different (P<0,05) using two-tailed t-tests

Habitat Variable	Torrented Reaches (N=9)	Flood Damaged or Torrented Reaches With New LOD Added (N=6)	Non-Torrented Reaches (N=9)
Riffle/Cascades (%)	66.6[a]	60.9[b]	43.1[a,b]
Glides (%)	9.5[a]	12.8	20.3[a]
Pools (%)	23.9	26.3	36.5
Lateral Scour	12.8	15.4	11.9
Plunge	1.5[a,b]	6.6[a]	8.5[a,b]
Dammed	1.3	1.1	6.5
Backwater	2.2	0.7	3.3
Under scour	0.0	0.0	0.8
Trench	5.6	1.7[a]	6.3a
Side	0.4	1.5	0.9
LOD Controlled Pool Area (%)	13.7	14.6	25.6
Boulder Controlled Pool Area (%)	8.5	1.2	7.9
Overwinter Pool Area	4.4[a]	9.2	21.2[a]
No. Pool Types	2.8a	3.3	4.3[a]
Diversity Index (d)			
Overall	1.48[a]	1.74[b]	2.30[a,b]
Pool	1.03[a]	1.21	1.70[a]
Overwintering	0.38[a]	0.69[b]	1.36[a,b]

P<0.05). This was primarily the result of the increase in riffle areas and a decrease in pool/glide areas. Because of the shift from LOD to boulders as the major scouring agents, pool diversity and overwinter habitat diversity also declined in torrented reaches—from 1.70 to 1.03 in the case of pool habitats (P<0.05) and from 1.36 to 0.38 in the case of overwinter habitats (P<0.05). The latter included any plunge, dammed, backwater, underscour or side channel pools controlled by LOD. With few exceptions, neither lateral scour nor trench pools were included as overwinter habitat in torrented streams, because only rarely did they appear capable of affording juvenile fish any significant protection from high flows in the absence of LOD.

The amount of overwinter habitat, like overwinter habitat diversity, also declined significantly in torrented stream reaches, from 21.2% down to 4.4% (P<0.05)(Table 14). This represents an average net loss in overwinter habitat of approximately 79% (range 15-100%), and is probably a better indication of the overall effects of debris torrents on juvenile survival and smolt production than the 38-45% reductions in total pool area described earlier under

TABLE 15. Chi-square analysis of the number of pools controlled by LOD, boulders, streambanks, and bedrock in torrented and non-torrented streams

Pool control		Stream type: Torrented	Flooded/ rehabilitated	Non-torrented	Total
LOD	Observed	31	54	61	146
	Expected	47.3	47.9	50.9	
	Chi-square	5.6	0.8	2.0	
Boulder	Observed	36	7	11	54
	Expected	17.5	17.7	18.8	
	Chi-square	19.6	6.5	3.2	
Streambank	Observed	7	14	9	30
	Expected	9.7	9.8	10.5	
	Chi-square	0.8	1.8	0.0	
Bedrock	Observed	4	4	3	11
	Expected	3.6	3.6	3.8	
	Chi-square	0.0	0.0	0.2	
Total		78	79	84	241

$X^2 = 40,7, 6 df, P<0.005$

the synoptic survey results (Sections 4.1.2 and 4.1.3). In the most severely affected stream studied (Macmillan Creek), the total amount of suitable overwintering habitat available for the entire accessible portion of the stream averaged 0.4% of the stream area, an estimated decline of 98%. In the least affected torrented stream studied (Saltspring Creek), the debris torrent jam formed in 1978 approximately 450 m upstream from the mouth subsequently failed over two winters in 1982/83 and 1983/84. The amount of overwinter habitat lost as a result was estimated at 45.5%, ranging from 62.7% in the upper one-third of the stream below the jam, to 14.6% in the lowermost one-third above the mouth.

4.2.2 Juvenile fish cover

There were few significant differences in the summer cover characteristics of torrented and non-torrented streams (Table 16). Generally speaking, non-torrented streams had more rootwads, LOD, SOD, undercut banks, and deep water cover, while torrented streams had more rock and boulder cover accompanied by surface turbulence. Both stream types had

TABLE 16. Comparisons of the summer cover in torrented, intermediate (flood-damaged and partially rehabilitated torrented streams), and non-torrented stream reaches. Mean values with the same superscripts are significantly different (P<0.05) using two-tailed t-tests

Summer cover	Stream reach type: Torrented (N=9)	Intermediate (N=6)	Non-torrented (N=9)
Rootwads(%)	1.1 ± 1.8	0.2 ± 0.4[a]	1.5 ± 1.4[a]
Large organic debris(%)	10.7 ± 7.0	12.0 ± 8.8	15.8 ±10.9
Small organic debris(%)	1.9 ± 1.5	1.9 ± 1.5	2.9 ± 2.3
Overhanging vegetation(%)	14.4 ±20.0	4.9 ± 5.6[a]	13.7 ± 5.9[a]
Undercut banks(%)	1.2 ± 2.3	0.6 ± 0.2	1.9 ± 1.2
Rocks(%)	7.1 ± 7.0	3.2 ± 1.8	4.1 ± 3.1
Surface turbulence(%)	3.0 ± 2.6	2.8 ± 2.0	2.2 ± 1.3
Deep water(%)	4.4 ± 4.3[a]	3.7 ± 1.8[b]	11.6 ± 5.1[a,b]
Total(%)	43.8 ±14.4	29.3 ±11.7	53.6 ±16.0[a]
Diversity($\bar{d}$)	1.96± 0.58	2.23± 0.20	2.35± 0.18

about the same amount of overhanging vegetation (13.7-14.4%). Deep water cover, ranging from 11.6% of the total wetted surface area in non-torrented streams to 4.4% in torrented streams, was the only single summer cover characteristic to differ significantly (P<0.05). Total cover area ranged from 53.6% of the wetted area in non-torrented streams to 43.8% in torrented streams, but the differences were not significant (P>0.05).

Intermediate stream reaches (i.e., those in Piper and upper Southbay Dump creeks where new LOD was added to the stream) had significantly less cover overall (29.3%, P<0.05) than non-torrented streams, primarily because of significantly lower amounts of deep water cover (3.7% vs 11.6%) and overhanging vegetation (4.9% vs 13.7%). Rootwad cover was also significantly lower (0.2% vs 1.5%), although the differences in this case were small and contributed little to the difference in total cover.

Winter cover in non-torrented streams was more abundant and complex than in torrented streams (P<0.05)(Table 17), while intermediate reaches generally had intermediate values. Although all streams shared about the same amount of boulder cover in LOD controlled pools, non-torrented streams had significantly more rootwad, undercut bank, and deep-water cover. The total amount of winter cover present in non-torrented streams was four times greater than the in torrented streams (I7.8% vs 4.4%, or 75.3% less, P<0.05). In intermediate streams, by comparison, winter cover averaged 8.6% — about twice the amount present in torrented steams and half the amount in non-torrented streams.

Differences between the amount of summer and winter cover present was greatest in debris torrented streams. Winter cover in non-torrented and intermediate streams, for

example, averaged 29-33% of the summer cover present, whereas torrented streams averaged only 10%. They also had higher proportions of what was considered "good cover" (e.g., LOD and boulders) located in unsuitable habitat such as riffles, glides, cascades, and "pocket" or cascade-like trench pools.

Cover diversity declined in torrented streams from 1.57 to 0.92 ($P<0.05$)(Table 17), which indicated that not only do non-torrented streams have more winter cover overall, but they also exhibit a wider and more even range of cover types. There were no undercut banks associated with LOD controlled pools in any of the torrented reaches examined, and only rarely were rootwads present. In addition, the LOD cover located in pools of non-torrented streams was almost always associated with abundant deep water cover. In contrast, the pools formed at LOD accumulations in torrented streams were comparatively small and shallow in relation to the amount of debris present, in part because many pools in torrented streams are transient—present one season and gone the next.

4.2.3 LOD characteristics

There were no significant differences between the mean average length (range 2.9-3.4 m) or diameter (range 0.38-0.42 m) of the LOD present in torrented and non-torrented stream reaches, and consequently no major differences in the mean average volume or stream area covered by a single piece of LOD (Table 18). Whatever differences existed between total LOD volumes or areas in the three different stream types (all of which were logged) were almost entirely attributable to differences in the actual number of LOD pieces present per unit of stream length. While non-torrented reaches averaged 0.50 pieces per metre of stream, intermediate-type reaches averaged 0.30 pieces and torrented reaches only 0.19 pieces — a decrease of 72% ($P<0.05$).

There were also significant differences in how LOD was positioned in relation to stream flows in torrented and non-torrented streams ($P<0,05$) (Table 19). Where torrented reaches had a relatively greater number of pieces oriented diagonally across the stream (46% vs 29%), non-torrented reaches had more LOD arranged cross-stream perpendicular to stream flows (41% vs 30%). Torrented reaches also had comparatively more LOD suspended over the stream channel (54% vs 44%), while non-torrented reaches had more LOD pieces buried in the channel substrate (18% vs 10%). With the last configuration, localized scouring was increased downstream of the LOD and sediments were stored upstream.

TABLE 17. Comparisons of the winter cover in torrented, intermediate (flood-damaged and partially rehabilitated torrented streams), and non-torrented stream reaches. Values with the same superscripts are significantly different ($P<0.05$) using two-tailed t-tests

Winter cover	Stream reach type: Torrented (N=9)	Intermediate (N=6)	Non-torrented (N=9)
Rootwads(%)	0.3 ± 0.4[a]	0.2 ± 0.4	1.0 ± 0.9
Large organic debris(%)	2.4 ± 3.1	5.6 ± 3.6	7.3 ± 8.6
Undercut banks(%)	0.0 ± 0.0[a]	0.3 ± 0.2[b]	1.3 ± 1.1[a,b]
Rock(%)	0.3 ± 0.6	0.6 ± 0.3	0.4 ± 0.2
Deep water(%)	1.8 ± 2.4[a]	2.0 ± 1.3[b]	7.8 ± 5.0[a,b]
Total(%)	4.4 ± 4.5[a]	8.6 ± 3.3	17.8 ±11.2[a]
Diversity($\bar{d}$)	0.92 ± 0.64[a]	1.45 ± 0.12	1.57 ± 0.28[a]

TABLE 18. Comparisons of the mean average number and size (±1 SD) of LOD pieces present in torrented, intermediate, and non-torrented logged stream reaches

LOD	Stream reach type: Torrented (N=9)	Intermediate (N=6)	Non-torrented (N=9)
Total no. pieces	261	335	627
No. pieces/m of stream	0.19 ± 0.11[a]	0.30 ± 0.09	0.50 ± 0.38[a]
Length(m)	3.1 ± 0.7	2.9 ± 0.5	3.4 ± 1.2
Diameter(m)	0.42 ± 0.08	0.38 ± 0.13	0.38 ± 0.05
Volume(m^3)	0.66 ± 0.31	0.65 ± 0.66	0.75 ± 0.46
Area(m^2)	1.31 ± 0.41	1.19 ± 0.68	1.36 ± 0.60

[a]Significantly different values, $P<0.05$.

TABLE 19. Chi-square analysis of the distribution of LOD in relation to stream flows in torrented and non-torrented stream reaches

		LOD orientation to streamflow(±30°)			
		Parallel	Diagonal	Perpendicular	Total
Torrented	Observed	54	100	65	219
	Expected	62.31	73.71	82.99	
	Chi-square	1.11	9.38	3.90	
Non-torrented	Observed	181	178	248	607
	Expected	172.69	204.29	230.01	
	Chi-square	0.40	3.38	1.41	
Total		235	278	313	826

$X^2 = 19.58$, df=2, $P<0.005$

		Streamflow deflection in relation to LOD			
		Under	Alongside	Over	Total
Torrented	Observed	125	84	24	233
	Expected	108.47	88.00	36.53	
	Chi-square	2.52	0.18	4.30	
Non-torrented	Observed	267	234	108	609
	Expected	283.52	230.00	95.47	
	Chi-square	0.96	0.07	1.64	
Total		392	318	132	842

$X^2 = 9.67$, df=2, $P<0.01$

5. DISCUSSION

The results of this study indicate that almost any form of mass wasting that causes torrent-like conditions in first- and second-order perennial streams substantially reduces both the quantity and quality of the rearing habitat available to juvenile salmonids, with probably the greatest impacts felt in reaches with less than 7% gradient. Debris torrents effectively reduced average net pool depth in these sections by an estimated 20-24%, pool area by 38-45%, LOD cover by 57%, and undercut bank cover by 76% (Fig. 6). At the same time, riffle area was increased by an average 47-57%, while rooted width was increased by 48-77%. More significantly, the amount of pool area typically regarded as good overwintering habitat for salmonid juveniles, particularly coho, was reduced by an average 79%, while the amount of winter cover itself was reduced by 75%. Since, in most cases, the amount of winter habitat available determines the number of smolts a stream can produce, presumably smolt production would end up reduced by the same amount (declines from overfishing and underseeding aside) (see Cederholm *et al.* 1981).

5.1 Factors Influencing Habitat Alterations

Much of the rearing habitat lost in streams directly affected by mass wasting is lost because either too much or too little sediment is left behind. Because there is usually also a reduction in the number of LOD pieces present—and therefore a reduction in LOD's ability to buffer sediment movements downstream—the impact is increased. LOD is probably the only factor that can effectively mitigate the effects of too little or too much sediment in streams on the Queen Charlotte Islands. As shown earlier by the pool/LOD area relationship in Figure 5 (Section 4.1.6), sites which managed to retain relatively large amounts of instream LOD after being affected by debris torrents and slides, were able to re-establish the same amount of pool habitat as that found at comparable sites without mass wasting one winter (Bonanza Creek) and three winters (Riley Creek) after. Although dewatering due to excess sediments was a contributing factor to the high amount of pool area recorded in Bonanza and Riley creeks, equally important was the fact that both streams had considerably more debris in them than other streams subjected to mass wasting.

Unlike other streams affected by mass wasting, the Bonanza and Riley Creek sites were both located in relatively wide, low gradient parts of the valley. This means that the study reaches were less directly affected by torrents than by material transported and deposited downstream during storm flows. Much of the debris and sediments spread out into large fan-shaped deposits. At some points on Riley Creek these deposits were over 100 m wide. Initially very little debris was evident at each site, but each downcutting has since exposed significant quantities of logging debris that was transported downstream (by the torrents) and old LOD buried by aggraded stream sediments.

Much of the LOD deposited in the Bonanza and Riley Creek study sites was arranged in criss-cross fashion, which further helped to create a large number of pools. This was in contrast to Mosquito Creek tributary, also a mass wasted stream with substantial quantities of LOD, which had relatively little pool area. Unlike Riley or Bonanza Creek, the LOD in Mosquito Creek tributary tended to be concentrated into a few large jams alongside the wetted channel, or arranged parallel to the direction of stream flow (Hogan 1986). Neither configuration satisfactorily promotes the scour conditions necessary to form pools.

The differences described in this study on the orientation and position of LOD in mass and non-mass wasted streams on the Islands are consistent with those reported by Hogan (1986) for logged and unlogged streams there. Like logging, debris torrents further reduce the overall complexity of stream habitats by shifting the remaining LOD around and reducing the number of points where localized scouring and sediment storage can occur. With a reduction in the number of LOD pieces, whatever sediment storage sites are formed tend to have a higher than normal share of the total sediment load, a higher chance of failing, and thus a greater risk of further damaging stream habitats when they do fail.

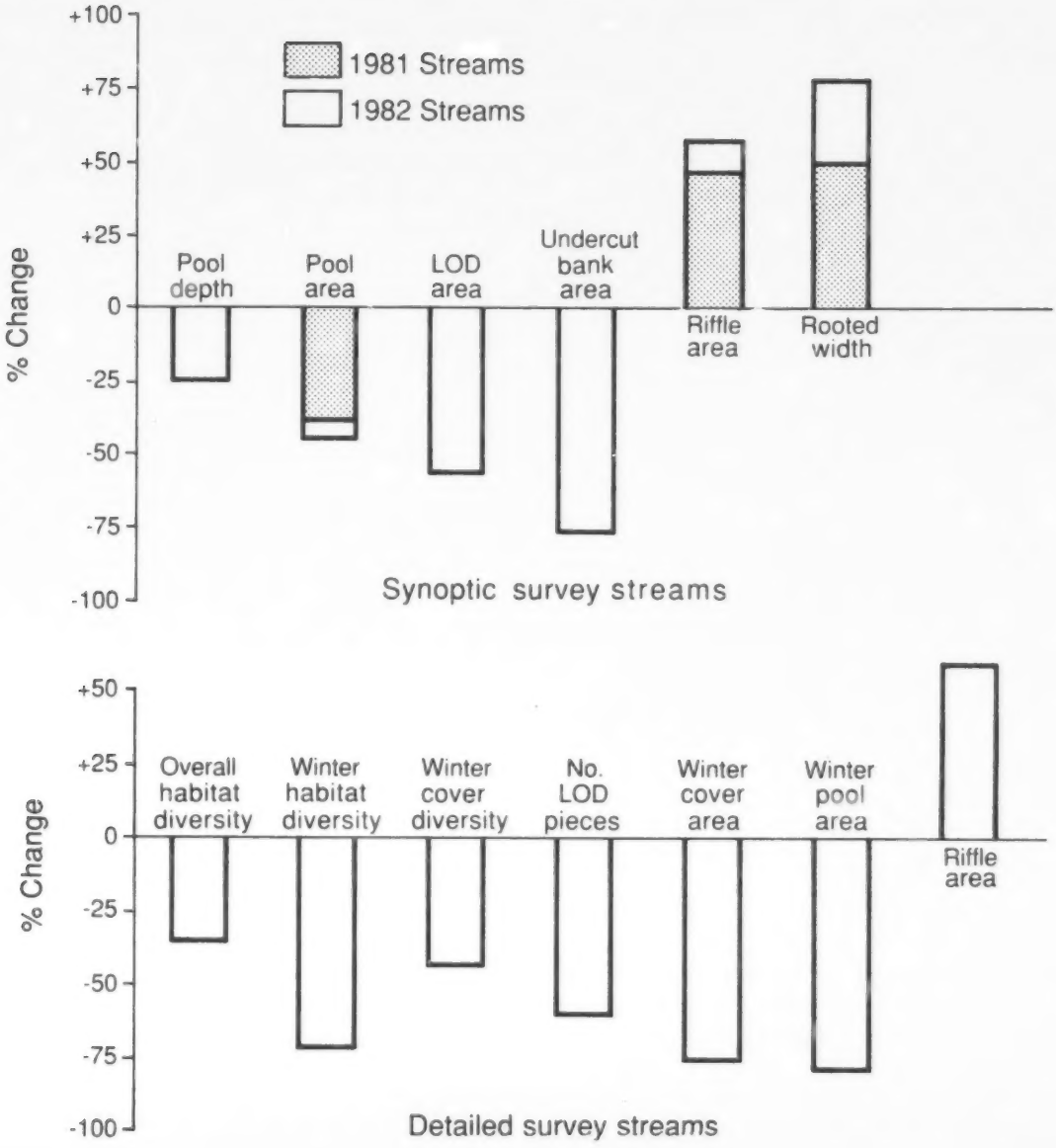

FIGURE 6. Juvenile fish habitat characteristics significantly altered by mass wasting in Study Streams on the Queen Charlotte Islands.

5.1.1 Sediment transport zones

Although not distinguished in this study, stream reaches with gradients over 3.5% (the mean gradient recorded at the terminus of debris torrents) tended to be sediment transport zones. When affected by mass wasting, fish habitats in these reaches were lost primarily because the fill originally stored in gravel bars and riffles was gouged out and carried downstream, along with substantial portions of the adjacent streambanks and the instream LOD. The LOD controlled pools were lost as a result, and replaced by coarse, bouldery substrates resistant to any further scouring.

New gravel has to be intercepted and stabilized to form new pools in debris torrented transport zones. The LOD left in these reaches, however, tends to be less efficient at trapping gravel than before. Instead of being partly submerged in the water, for example, LOD in mass wasted streams is more likely to be perched above the water on boulders and gravel bars. Likewise, instead of being oriented across the stream, perpendicular to the direction of stream flow and gravel movement, it is more likely to be positioned parallel or diagonally to them. As suggested earlier, new boulder controlled pools compensate partially for the loss of debris controlled pools, but probably only during low flow periods. At high flows, the ability of shallow boulder controlled pools to serve as juvenile coho overwinter habitat is probably as limited as their ability to trap and stabilize gravel moving downstream (Megahan 1982).

The amount of habitat present in accessible reaches with gradients over 7% was not examined in great detail, particularly in non-mass wasted streams. For parameters such as LOD cover, stream width, and undercut banks, the values recorded in high gradient torrented reaches were effectively the same as those recorded in torrented low gradient reaches, and thus related poorly to gradient. Other habitat features, however, were so restricted by gradient that differences between mass and non-mass wasted streams were sometimes small and difficult to demonstrate statistically. Differences in pool area between mass and non-mass wasted streams, for example, were absent altogether at gradients over 7%.

5.1.2 Sediment deposition zones

When affected by mass wasting, reaches with stream gradients less than 3.5% tended to be depositional zones. Here, habitat was lost not because of excess scouring, but because excess sediments filled in the channel and overtopped the streambanks. Pools were lost or simplified because they were filled in. Although there was abundant gravel for the formation of new pools, the necessary scouring agents were usually lacking because they were either buried, pushed up alongside the valley walls, or concentrated into a few large jams. Further bank erosion and infilling often occurred in affected study reaches as a result of lateral shifts in the channel, while other sediments were frequently added as a result of secondary torrents and valley wall failures upstream.

During summer and winter low flows, dewatering resulting from increased subterranean flows was frequently a serious problem in channels containing excessive sediment loads. Such a problem no doubt contributes to the high pool/riffle and rooted to wetted stream width ratios sometimes observed in mass wasted streams. However, because it was rarely quantified in this study, the amount of habitat lost to dewatering is unknown. Small streams used by coho or trout are especially sensitive to dewatering, particularly if there has also been a significant reduction in the amount of LOD present. Compared to large streams, dewatering caused by sediment depositions in small streams is likely to occur for longer periods because of lower flows and a lower carrying capacity for sediment. It is also likely to affect relatively greater proportions of stream area and therefore more critical areas, because the range of habitat types and the possibilities for their duplication are more restricted.

Possible effects of dewatering on juvenile fish include a greater incidence of entrapment or stranding in isolated channels and pools which subsequently dry up. Where cover is

lacking, there may also be increased predation as fish become concentrated into progressively smaller areas, and increased competition as fish are forced into more intimate contact with one another and food supplies dwindle. Pre-spawning adult fish are also likely to be entrapped more often during fall low flows, thereby increasing the frequency of salmon die-offs like those described by Murphy (1985) in southeast Alaska. Similarly, lower than normal winter flows may substantially reduce egg-to-fry survival, especially after hatching (Becker *et al.* 1983).

5.2 Effects of Logging

Downstream of directly affected stream reaches, there were no obvious changes to fish rearing habitats, apart from those caused by logging. From the synoptic survey data, effects attributed strictly to logging included a 27% reduction in LOD cover or about half the amount removed by mass wasting, and a 74% reduction in undercut bank area, about the same amount removed by mass wasting. These results are consistent with those in Carnation Creek on Vancouver Island, where Toews and Moore (1982a) reported substantial increases in the amount of bank erosion in logged areas lacking buffer strips. More recently, Koski *et al.* (1984) reported significant declines in undercut bank area in both clearcut and buffered reaches of Alaskan streams, with the greatest reduction in clearcut reaches.

When previously logged first- and second-order streams are first damaged by debris torrents, the upper two-thirds of the stream accessible to migrant fish is usually affected. In unlogged streams, the damage is more often contained within the upper one-third of the accessible part of the stream. Why debris torrents should move further downstream in logged areas is not clear at this time. Many studies besides the present one have shown that logging up to the streambanks frequently increases bank erosion, reduces the amount or stability of the LOD component (Toews and Moore 1982a), and permits the mobilization of large quantities of inchannel sediments (Roberts 1984). It seems likely that torrents passing through logged areas not only meet less resistance because the amount of stable LOD present is reduced, but also pick up greater quantities of sediment and debris than those in unlogged areas. Presumably this would increase the momentum of "logged area" torrents, and hence their ability to move greater distances downstream, penetrating further into low gradient reaches used by migrant fish.

The values reported in this study are minimum estimates of the amount of productive habitat likely to be lost as a result of torrenting — minimum because they reflect only the habitat lost immediately after a torrent occurs. Unless removed or by-passed by the stream somehow, the debris that generally forms at the terminus of a debris torrent will eventually fail again as the jam starts to decay and debris and sediments erode away. When this occurs, the impacts to the downstream channel appear similar to those of the original event, often nullifying whatever recovery has occurred since the stream was first affected. In fact, recurrent mass wasting in the form of additional debris torrents, slides, and flows appears to be relatively common in affected streams and should be recognized when the potential long-term impacts of mass wasting in debris torrented streams, and the feasibility of rehabilitating affected streams, are being assessed.

5.3 Duration of Effects

Precisely how long debris jams in logged areas are likely to last is unknown, but the observations in this study suggest that 3-5 years is probably an acceptable minimum estimate. Of eleven 2-year-old debris jams examined in 1981, 10 were considered impassable by fish. Three winters later, at least one jam had collapsed (e.g., Saltspring Creek), while two others exhibited substantial breaks (Schomar Creek and upper Southbay Dump Creek). The following winter in 1985, a 9 m high jam located 900 m upstream from the mouth of Southbay Dump Creek failed completely and re-torrented approximately 750 m of the channel.

Because unfelled timber is involved, debris torrent jams in unlogged areas probably last for much greater periods than those in logged areas. In one headwater tributary to Government

Creek (an unlogged stream) there were three different debris jams, and the two most recent (4 and 11 years old) were still intact and clearly impassable by fish in 1983. Although the oldest jam (42+ years) had broken down considerably, it still had a drop of about 1.25 m and was probably impassable by juvenile fish at all flows, and passable by adult fish only during high flows. In another example, 85-year-old alders were found growing on what was once the forebay of a large reservoir formed behind a slide into Hangover Creek. Since the slide itself was about 155 years old (Smith *et al.* 1986), the slide probably blocked off Hangover Creek for close to 70 years before downcutting enough to drain the forebay area. Because the slide was not only the oldest but also the largest slide investigated by Smith *et al.* (1986) in an extensive survey of slides on the Queen Charlotte Islands, 70 years is probably close to the maximum expected lifespan of a jam formed by mass wasting in this region.

5.4 Effects on Fish

The damage inflicted by debris torrents on the rearing habitats of directly affected stream reaches is severe enough to compromise their ability to support juvenile fish (barriers to upstream areas and tributaries notwithstanding). This is particularly true during the winter period when survivals are often simply related to the amount of cover fish can use to escape hazardous flow conditions (Skeesick 1970; Bustard and Narver 1975; Tschaplinski and Hartman 1983; Heifetz *et al.* 1986). Spring and summer survivals, in contrast, are usually regulated more by density dependent factors such as the number of feeding areas or amount of food available (Chapman 1966; Mason 1976; Ward and Slaney 1982).

Clearcut logging and removal of the canopy over forested streams have been shown, in some cases, to increase salmonid standing crops during the summer (Murphy and Hall 1981; Koski *et al.* 1984, Scrivener and Andersen 1984). This is due partly to short-term increases in the complexity of fish habitats in streams (Toews and Moore 1982b), and partly to increases in production at lower trophic levels (Chapman and Knudsen 1980; Newbold *et al.* 1980; Murphy *et al.* 1981). Presumably the same factors responsible for increases in productivity in logged streams (e.g., increased light illumination, higher water temperatures, and increased nutrient loading rates) would also occur in mass wasted streams, thereby alleviating some of the constraints on fish production caused by reductions in juvenile fish cover.

Juvenile densities in late summer in mass wasted streams on the Queen Charlotte Islands were almost as high as those in logged streams without mass wasting — and much higher than expected based on the amount of habitat available.[5] Winter survivals, however, were substantially lower and therefore more indicative of the overall impacts of mass wasting. Although logged, non-torrented streams had coho overwinter survivals averaging 18.8% (range 5.4-36.3%) and an average smolt production of 0.184 fish per lineal metre of stream, average survival in logged, debris torrented streams was only 1.8% (range 1.7-1.9%), with an average smolt production of 0.023 fish per lineal metre.[6] Rainbow trout and Dolly Varden char survivals were less affected than coho, a difference attributed by the authors of this report to their greater affinity for faster water habitats (Murphy *et al.* 1982) and bouldery substrates (Bustard and Narver 1975) in shallow pools and undercut riffle margins.

For coho, the impacts of mass wasting on overwinter habitat appear to be so severe that overwinter survivals and smolt production in affected reaches may, in many cases, be too low to ensure an adequate return of adults. For streams similar to Macmillan Creek, where the entire stream was torrented and no other habitat exists other than that present in the main channel, the continued existence of an entire self-sustaining population is thus remote, at least until overwinter conditions improve. Even coho populations located in otherwise normal-looking stream reaches below a debris torrent may be at risk if subjected 3 years in a row (the mean generation time of coho) to major sediment releases passing downstream from decaying debris jams and sediment wedges.

5 Tripp and Poulin (1986a).

6 Ibid.

5.5. Rate of Recovery

The rate at which stream habitats recover from the effects of mass wasting — debris torrents in particular — was not examined in this study. Because of the critical role LOD plays in determining channel form, however, recovery is almost certain to be slowest in streams that have had the most LOD removed from the active channel; and where streamside logging practices severely restrict the addition of new LOD, at least until the first trees (alder in most cases) in the successional development of the riparian zone mature and start to die. Even then recovery may never be complete. With rotational periods of approximately 70 years, it is questionable whether alder fall and young conifers can supply the LOD needed to achieve the same level of fish production as occurs in pristine streams.

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TABLE A1. Summary of 1981 study reach characteristics

Stream	Reach No.	Stream Length (km)	Basin Area (km^2)	Reach[1] Location (m)	Reach Length (m)	Reach Gradient (%)	% Basin Logged	Period[2] Reach Logged	Period Upper Reaches Logged	Mass Wasting	Remarks
					Unlogged, No Mass Wasting						
Newcombe Inlet	1	1.4	2.0	0	460	9.2	0	Unlogged	Unlogged	None	
Phantom Trib.	1	1.7	4.1	270	370	2.7	0	Unlogged	Unlogged	Upstream	1978-79 debris torrent
Windy Bay Trib.	1	1.7	2.7	0	640	2.9	0	Unlogged	Unlogged	Upstream	
					Unlogged, Mass Wasting						
Phantom Trib.	2	1.7	4.1	640	225	6.1	0	Unlogged	Unlogged	Instream	1978-79 debris torrent
Windy Bay Trib.	2	1.7	2.7	640	460	9.9	0	Unlogged	Unlogged	Instream	
					Old Logging, No Mass Wasting						
Beljay	1	1.9	2.1	0	400	3.3	14	S1933-34	Unlogged	None	Stream channelized, no cover
Clew	1	2.3	3.4	650	520	3.5	36	A1940-50	H1978-81	Upstream	1978-79 debris torrent
Landrick	1	1.1	2.3	0	450	3.8	43	A1936	H1978-81	None	
Mosquito Lk. Trib.	1	3.7	3.8	0	560	1.2	61	H1950's	H1960-74	Upstream	1978-79 debris torrent
Richardson	1	2.4	3.8	0	1200	3.0	24	S1935	H1977-81	None	Sediments unstable, banks eroded
Richardson	2	2.4	3.8	1200	700	6.1	24	S1935	H1977-81	None	Sediments unstable, dewatering common
Richardson	3	2.4	3.8	1900	400	12.4	24	S1935	H1977-81	None	Sediments unstable, dewatering common
Sachs	1	10.0	17.8	0	1100	0.8	62	Pre-1956	H1974-81	Upstream	1974 debris torrent
Sachs	2	10.0	17.8	1100	800	1.7	62	Pre-1956	H1974-81	Upstream	1974 debris torrent
Sandy Main	1	4.4	6.5	500	500	2.0	9	S1933	H1970-78	Upstream	1978-79 debris torrent

Continued

TABLE A1 Continued

Stream	Reach No.	Stream Length (km)	Basin Area (km^2)	Reach[1] Location (m)	Reach Length (m)	Reach Gradient (%)	% Basin Logged	Period[2] Reach Logged	Period Upper Reaches Logged	Mass Wasting	Remarks
Takelly	1	1.4	2.1	0	540	1.5	35	A,S1918	S1933-34	None	Stream channelized, little cover
Talunkwan	1	3.0	3.9	20	360	2.3	36	A1945	H1969-76	Upstream	1978-79 debris torrent
Tarundl	1	6.7	11.0	0	540	1.5	37	H1964-67	H1972-81	None	
Thurston	1	4.7	6.1	0	700	2.0	72	A,S1939-48	1968-75	Upstream	1978-79 debris torrent
						Old Logging, Mass Wasting					
Clew	2	2.3	3.4	1170	600	9.7	36	A1940-50	H1978-81	Instream	1978-79 debris torrent
Macmillan	1	4.9	6.2	0	400	3.1	77	H1946	H1976-81	Instream	1978-79 debris torrent
Mosquito Ck. Trib.	1	5.2	5.4	400	740	2.5	20	H1960's	H1960's	Instream	Banks severely eroded, slides
Mosquito Lk. Trib.	2	3.7	3.8	560	560	2.6	61	H1950's	H1960-74	Instream	1978-79 debris torrent
Mosquito Lk. Trib.	3	3.7	3.8	1120	520	7.8	61	H1950's	H1960-74	Instream	1978-79 debris torrent
Powrivco Bay	1	0.9	1.1	0	430	8.4	47	A1933-34	H1977-78	Instream	1978-79 debris torrent
Sachs	3	10.0	17.8	1900	440	2.5	62	H1974	H1974-81	Instream	1974 debris torrent
Southbay	1	4.1	4.0	0	420	2.6	82	H1960	H1961-80	Instream	Debris torrented 1978-79, flooded 1983, retorrented 1985
Southbay	2	4.1	4.0	420	280	6.1	82	H1961-68	H1961-80	Instream	Debris torrented 1978-79, flooded 1983, retorrented 1985
Upper Mathers	1	3.1	19.0	1950	560	5.2	8	A1940-50	Unlogged	Instream	Old slides (1950's)
						New Logging, No Mass Wasting					
Little Goose Trib.	1	0.9	0.5	100	280	3.1	> 35	H1973	H1973-78	Upstream	1978-79 debris torrent

Continued

TABLE A1 Concluded

Stream	Reach No.	Stream Length (km)	Basin Area (km^2)	Reach[1] Location (m)	Reach Length (m)	Reach Gradient (%)	% Basin Logged	Period[2] Reach Logged	Period Upper Reaches Logged	Mass Wasting	Remarks
Sandy Left	1	1.5	1.6	20	400	7.0	25	H1970	Unlogged	None	
Sandy Right	1	1.1	1.6	50	260	6.3	No Data	H1978	H1970	Upstream	
Tarundl	2	6.7	11.0	1600	500	4.0	37	H1972-78	H1972-81	None	
						New Logging, Mass Wasting					
Macmillan	2	4.9	6.2	2400	500	12.0	77	H1977-78	H1976-81	Instream	1978-79 debris torrent
Sandy Right	2	1.1	1.6	310	260	8.1	No Data	H1970	No Data	Instream	1978-79 debris torrent
Talunkwan	2	3.0	3.9	380	880	8.4	36	H1969	H1970-76	Instream	1978-79 debris torrent
Thurston	2	4.7	6.1	1900	480	2.0	72	1948-H68	H1971-75	Instream	1978-79 debris torrent

[1]Distance from mouth to lower reach boundary

[2]A = A-frame logging; S = skidder logging; H = high lead logging

TABLE A2. Summary of 1982 study reach characteristics

Stream	Reach No.	Stream Length (km)	Basin Area (km^2)	Reach[1] Location (m)	Reach Length (m)	Reach Gradient (%)	Basin Logged	Period[2] Reach Logged	Period Upper Reaches Logged	Mass Wasting	Remarks
Unlogged, No Mass Wasting											
Cache	1	1.7	1.5	0	450	2.5	33	Unlogged	H1975-81	None	
Cache	2	1.7	1.5	450	280	5.1	33	Unlogged	H1975-81	None	
Government	1	5.3	16.1	730	630	2.0	0	Unlogged	Unlogged	Upstream	Headwaters unstable; many debris torrents (1972-78)
Government Trib.	1	1.7	1.6	0	250	5.0	0	Unlogged	Unlogged	Upstream	1972, 1978 debris torrents upstream; 44+ year old torrent instream
Hangover	1	9.5	21.2	255	490	1.5	0	Unlogged	Unlogged	None	Massive 155+ year old slide upstream
Inskip	1	6.7	13.0	0	490	2.6	0	Unlogged	Unlogged	None	Old slides upstream
Marshall Head	1	2.8	2.3	0	270	3.9	0	Unlogged	Unlogged	None	
Matheson Head	1	3.6	6.7	0	500	1.1	0	Unlogged	Unlogged	Upstream	1979 debris torrent
Matheson Side	1	3.5	5.0	0	490	1.8	0	Unlogged	Unlogged	None	
Phantom	1	10.4	18.6	800	500	1.2	3	Unlogged	H1978-81	Upstream	1978-79 debris torrent in headwaters, also slides from logged area
Rennell Unnamed	1	5.3	11.3	0	500	3.5	0	Unlogged	Unlogged	None	
Salmon	1	5.4	10.7	0	600	1.5	0	Unlogged	Unlogged	None	
Skaat	1	1.0	1.6	0	240	6.0	0	Unlogged	Unlogged	None	
Windy Bay Trib.	1	1.7	2.7	0	640	2.9	0	Unlogged	Unlogged	Upstream	1978-79 debris torrent
Unlogged, Mass Wasting											
Government Trib.	2	1.7	1.6	250	250	7.0	0	Unlogged	Unlogged	Instream	1972, 1978 debris torrent

Continued

TABLE A2 Continued

Stream	Reach No.	Stream Length (km)	Basin Area (km^2)	Reach[1] Location (m)	Reach Length (m)	Reach Gradient (%)	% Basin Logged	Period[2] Reach Logged	Period Upper Reaches Logged	Mass Wasting	Remarks
Old Logging, No Mass Wasting											
Landrick	1	1.1	2.3	0	450	3.8	43	A1936	H1978-82	None	
Peel	1	4.6	11.6	0	410	1.2	15	H1950's	H1950's	None	
Peel	2	4.6	11.6	410	140	3.6	15	H1950's	H1950's	None	
Piper	1	4.8	4.2	0	600	2.2	10	A1955	H1976-79	None	Severe flood damage in 1983
Sachs	1	1.0	17.8	0	800	1.7	62	prel956	H1974-82	Upstream	1974 debris torrent
Schomar	1	3.4	6.6	0	400	2.1	36	H1965-67	H1970-76	Upstream	1978-79 debris torrents; debris jam failure in 1983-84
Talunkwan	1	3.0	3.9	0	360	2.3	36	A1945	H1969-73	Upstream	1978-79 debris torrents
Tarundl	1	6.7	11.0	0	540	1.1	37	H1964	H1964-82	None	
Thurston	1	4.7	6.1	0	700	2.0	72	A,S1939-48	H1968-75	Upstream	1978-79 debris torrent
Old Logging, Mass Wasting											
Macmillan	1	4.9	6.2	0	400	3.1	77	H1946	H1976-82	Instream	1978-79 debris torrent
Mosquito Ck. Trib.	1	5.2	5.4	400	740	2.5	20	H1960's	H1960's	Instream	Banks severely eroded, slides, torrents possible
Mosquito Lk. Trib.	2	3.7	3.8	560	560	2.6	61	H1950's	H1960-74	Instream	1978-79 debris torrent
Mountain	1	7.6	12.8	0	515	1.1	9	S1958	H1965-67	Instream	Banks severely eroded, slides
Saltspring	1	3.6	6.3	0	240	3.5	13	H1965	Unlogged	Instream	Debris torrented 1978-79, re-torrented 1981-82, 83-84
Saltspring	2	3.6	6.3	240	150	7.1	13	H1965	Unlogged	Instream	Debris torrented 1978-79, re-torrented 1981-82, 1983-84

Continued

TABLE A2 Concluded

Stream	Reach No.	Stream Length (km)	Basin Area (km²)	Reach Location[1] (m)	Reach Length (m)	Reach Gradient (%)	% Basin Logged	Period Reach Logged[2]	Period Upper Reaches Logged	Mass Wasting	Remarks
Southbay	1	4.1	4.0	0	420	2.6	82	H1960	H1961-80	Instream	Debris torrented 1978-79, flooded 1983, re-torrented 1985
Southbay	2	4.1	4.0	420	280	6.1	82	H1961-68	H1961-80	instream	Debris torrented 1978-79, flooded 1983, re-torrented 1985
Two Torrent	1	2.7	3.9	150	750	4.0	20	H1965-66 (est.)	H1965-66	Instream	Two debris torrents 1978-79
						New Logging, No Mass Wasting					
Riley	1	11.3	28.7	5150	300	2.5	12	H1974	H1977-80	Upstream	1978-79 debris torrents
Riley Trib.	1	3.3	4.0	0	495	4.1	3	H1974	Unlogged	None*	*Banks eroding, torrent-like conditions in stream
Tarundl	2	6.7	11.0	1600	500	3.5	37	H1972-78	H1978-82	None*	*5 m high debris jam at end of reach, strong evidence of major channel shift prior to logging
						New Logging, Mass Wasting					
Bonanza	1	13.9	47.4	4750	555	1.3	13	H1980-82	Unlogged	Instream	1981-82 debris slides
Riley	2	11.3	28.7	5450	400	1.8	12	H1974	H1977-80	Instream	1978-79 debris torrents (deposition zone only)
Shelley	1	4.1	5.4	0	495	2.9	17	H1972	H1973	Instream	1978-79 debris torrents

[1] Distance from mouth to lower reach boundary

[2] A = A-frame logging; S = skidder logging; H = high lead logging

TABLE A3. Channel width and pool, glide, and riffle surface area characteristics of Queen Charlotte Islands study streams, June 8-August 13, 1982

Stream	Reach	Date	Channel Width (m) Wetted	Channel Width (m) Rooted	Surface Area(m^2)	% of Surface Area Pool	% of Surface Area Glide	% of Surface Area Riffle
Unlogged, No Mass Wasting								
Rennell Unnamed	1	June 12	5.8	15.9	2,907	14	19	67
Matheson Side	1	June 22	4.0	25.5	1,943	43	41	16
Windy Bay Trib.	1	June 24	2.2	18.0	434	17	28	55
Windy Bay Trib.	2	June 24	1.9	13.6	837	27	52	21
Skaat	1	June 24	2.6	12.9	634	18	11	71
Matheson Head	1	July 11	7.5	18.8	3,745	43	31	26
Cache	1	July 12	3.8	6.5	1,730	35	33	32
Cache	1	July 12	4.5	6.4	1,268	28	12	60
Hangover	1	July 12	16.8	29.5	8,237	59	30	11
Marshall Head	1	July 12	7.3	17.7	1,958	23	10	67
Government	1	July 26	5.7	24.5	3,605	69	10	21
Inskip	1	July 30	8.0	55.1	3,904	46	25	29
Government Trib.	1	Aug 7	3.4	10.0	855	42	8	50
Phantom	1	Aug 12	11.5	32.1	5,727	43	31	26
Salmon	1	Aug 13	18.5	38.9	11,104	10	35	55
Unlogged, Mass Wasting								
Government Trib.	2	Aug 7	2.9	10.4	725	5	9	86
Old Logging, No Mass Wasting								
Tarundl	1	June 6	14.1	29.0	7,590	42	33	25
Landrick	1	June 21	2.8	11.0	1,232	43	6	51
Piper	1	June 29	2.6	7.7	1,575	22	36	42
Sachs	1	July 2	11.8	24.4	12,946	29	33	38
Thurston	1	July 18	2.8	8.0	1,946	57	17	26
Talunkwan	1	July 19	6.2	17.8	2,124	49	17	34
Schomar	1	July 19	7.1	17.6	2,821	37	29	34
Peel	1	July 29	5.6	15.0	2,285	53	14	33
Peel	2	July 29	6.9	21.0	968	53	9	38
Old Logging, Mass Wasting								
Southbay	1	June 8	2.9	24.7	1,222	9	17	75
Southbay	2	June 8	2.6	28.5	738	7	15	78
Two Torrent	1	June 17	2.9	9.9	2,173	15	16	70
Mosquito Lake	2	June 16	2.2	28.0	484	25	32	43
Macmillan	1	July 16	3.2	12.3	1,278	5	1	94
Mosquito Ck Trib.	1	July 22	5.7	23.4	4,208	31	19	50
Mountain	1	Aug 6	8.2	34.9	4,228	14	16	70
Saltspring	1	Aug 6	3.7	41.9	897	21	25	54
Saltspring	2	Aug 6	5.7	74.3	860	10	22	68
New Logging, No Mass Wasting								
Tarundl	2	June 7	5.7	11.6	2,846	16	22	62
Riley Trib.	1	July 12	4.8	11.0	2,365	8	14	78
Riley	1	July 26	7.0	29.3	2,107	68	21	11
New Logging, Mass Wasting								
Bonanza	1	July 9	7.5	24.7	4,149	76	13	11
Shelley	1	July 11	3.6	19.9	1,788	23	41	36
Riley	2	July 26	9.4	44.1	3,748	70	22	8

TABLE A4. Channel width and pool, glide, and riffle surface area characteristics of Queen Charlotte Islands study streams, July 14-September 22, 1981

Stream	Reach	Date	Channel Width (m) Wetted	Channel Width (m) Rooted	% of Surface Area Pool	% of Surface Area Glide	% of Surface Area Riffle
Unlogged, No Mass Wasting							
Phantom Trib.	1	Aug 6	3.7	12.2	44	12	44
Windy Bay Trib.	1	Aug 12	1.9	8.7	26	5	69
Newcombe Inlet	1	Aug 18	2.8	8.7	7	15	78
Unlogged, Mass wasting							
Phantom Trib.	2	Aug 6	2.7	32.0	18	3	79
Windy Bay Trib.	2	Aug 12	1.6	20.1	36	13	51
Old Logging, No Mass Wasting							
Tarundl	1	July 15	6.7	13.9	37	17	46
Mosquito Lk Trib.	1	July 18-23	2.9	6.7	57	16	27
Richardson	1	Aug 1	1.1	12.0	27	8	65
Richardson	2	Aug 1	3.1	12.5	11	0	89
Richardson	3	Aug 1	0.8	11.4	11	0	89
Clew	1	Aug 7	3.2	12.9	38	10	52
Sandy Main	1	Aug 10	4.4	15.9	40	9	51
Landrick	1	Aug 12	6.0	27.3	34	30	36
Beljay	1	Aug 13	3.5	7.7	7	5	88
Takelly	1	Aug 13	3.0	8.3	7	14	79
Thurston	1	Aug 15	3.9	7.8	57	20	23
Talunkwan	1	Aug 15	3.2	12.0	31	18	51
Sachs	1	Sept 22	ND	ND	24	50	13
Sachs	2	Sept 22	ND	ND	23	37	40
Old Logging, Mass Wasting							
Macmillan	1	July 14	3.2	22.8	15	20	65
Mosquito Ck Trib.	1	July 18	3.2	26.3	30	8	62
Mosquito Lk Trib.	2	July 18-23	4.5	32.3	14	8	78
Mosquito Lk Trib	3	July 18-23	ND	ND	41	10	48
Southbay	1	July 29	2.7	17.9	4	29	67
Southbay	2	July 29	2.5	19.9	ND	ND	ND
Mathers	1	Aug 7	3.2	16.8	18	15	67
Clew	2	Aug 7	3.4	18.5	15	8	77
Powrivco Bay	1	Aug 12	2.5	10.0	8	7	85
Sachs	3	Sept 22	ND	ND	14	32	54
New Logging, No Mass Wasting							
Tarundl	2	July 15	5.7	14.2	31	19	50
Sandy Left	1	Aug 10	2.8	5.5	33	15	52
Sandy Right	1	Aug 13	2.5	7.0	11	44	45
Little Goose Trib.	1	Aug 17	1.7	6.6	55	10	35
New Logging, Mass Wasting							
Macmillan	2	July 28	3.1	15.3	20	8	72
Sandy Right	2	Aug 13	2.3	8.0	19	1	80
Talunkwan	2	Aug 15	2.3	21.3	31	7	62
Thurston	2	Aug 15	2.6	15.2	28	32	39

TABLE A5. Maximum pool, glide, riffle depths and net pool depth (m) in Queen Charlotte Islands study streams, June 9-August 13, 1982

Stream	Reach	Date	Maximum Depth (m) Pool	Glide	Riffle	Net Pool Depth (m) (Max. Pool Depth - Max. Riffle Depth)
		Unlogged, No Mass Wasting				
Rennell Unnamed	1	June 12	1.07	0.61	0.60	0.47
Matheson Side	1	June 22	0.78	0.37	0.18	0.60
Windy Bay Trib.	1	June 24	0.41	0.26	0.17	0.24
Windy Bay Trib.	2	June 24	0.52	0.27	0.13	0.39
Skaat	1	June 24	0.59	0.33	0.26	0.33
Matheson Head	1	July 11	0.99	0.33	0.18	0.81
Cache	1	July 12	0.64	0.37	0.16	0.48
Cache	2	July 12	0.58	0.33	0.23	0.35
Hangover	1	July 12	1.14	0.85	0.24	0.90
Marshall Head	1	July 12	0.58	0.47	0.30	0.28
Government	1	July 26	0.80	0.36	0.17	0.63
Inskip	1	July 30	0.77	0.47	0.25	0.52
Government Trib.	1	Aug 7	0.53	0.25	0.16	0.37
Phantom	1	Aug 12	0.96	0.62	0.30	0.66
Salmon	1	Aug 13	1.40	0.35	0.44	0.96
		Unlogged, Mass Wasting				
Government Trib.	2	Aug 7	0.53	0.25	0.16	0.37
		Old Logging, No Mass Wasting				
Tarundl	1	June 6	1.10	0.61	0.41	0.69
Landrick	1	June 21	0.57	0.26	0.22	0.35
Piper	1	June 29	0.45	0.31	0.16	0.29
Sachs	1	July 2	0.94	0.57	0.26	0.68
Thurston	1	July 18	0.55	0.33	0.15	0.40
Talunkwan	1	July 19	0.59	0.28	0.18	0.41
Schomer	1	July 19	0.82	0.57	0.17	0.65
Peel	1	July 29	0.69	0.33	0.20	0.49
Peel	2	July 29	0.82	0.33	0.23	0.59
		Old Logging, Mass Wasting				
Southbay	1	June 8	0.45	0.27	0.35	0.10
Southbay	2	June 8	0.55	0.30	0.35	0.20
Mosquito Lake	2	June 16	0.62	No Data	0.27	0.35
Macmillan	1	June 16	0.53	0.35	0.27	0.26
Two Torrent	1	June 17	0.49	No Data	0.31	0.18
Musquito Ck. Trib.	1	July 22	0.77	0.43	0.27	0.50
Mountain	1	Aug 6	1.08	0.61	0.45	0.63
Saltspring	1	Aug 6	0.53	0.27	0.18	0.35
Saltspring	2	Aug 6	0.43	0.26	0.18	0.25
		New Logging, No Mass Wasting				
Tarundl	2	June 7	1.24	0.57	0.47	0.77
Riley Trib.	1	July 12	0.53	0.50	0.35	0.18
Riley	1	July 26	0.61	0.21	0.19	0.42
		New Logging, Mass Wasting				
Bonanza	1	July 9	0.88	0.49	0.19	0.69
Shelley	1	July 11	0.56	0.38	0.24	0.32
Riley	2	July 26	0.81	0.37	0.29	0.52

TABLE A6. Stable undercut bank cover in pools, glides, and riffles of Queen Charlotte Islands study streams, June 9-August 13, 1982

Stream	Reach	Date	Undercut Bank Area (m^2) Pool	Glide	Riffle	Total	% of Total Wetted Area
		Unlogged, No Mass Wasting					
Rennell Unnamed	1	June 12	5.0	15.0	13.0	33.0	1.1
Matheson Side	1	June 22	33.5	51.0	1.0	85.5	4.4
Windy Bay Trib.	1	June 24	6.0	4.5	9.5	20.0	4.6
Windy Bay Trib.	2	June 24	13.0	20.5	8.5	42.0	5.0
Skaat	1	June 24	4.0	3.0	12.0	19.0	3.0
Matheson Head	1	July 11	25.5	20.0	13.0	58.5	1.6
Cache	1	July 12	29.0	70.0	15.0	114.0	6.6
Cache	2	July 12	24.0	16.0	30.0	70.0	5.5
Hangover	1	July 12	37.0	46.0	8.0	91.0	1.1
Marshall Head	1	July 12	17.0	3.0	81.0	101.0	5.1
Government	1	July 26	111.0	4.0	12.0	127.0	3.5
Inskip	1	July 30	13.0	15.0	11.0	39.0	1.0
Government Trib.	1	Aug 7	4.0	0.0	6.0	6.0	0.7
Phantom	1	Aug 12	44.0	24.0	33.5	102.0	1.8
Salmon	1	Aug 13	8.0	27.0	32.0	67.0	0.6
		Unlogged, Mass Wasting					
Government Trib.	2	Aug 7	5.0	1.0	5.0	6.0	0.8
		Old Logging, No Mass Wasting					
Tarundl	1	June 6	84.5	59.0	17.5	161.0	2.1
Landrick	1	June 21	8.0	1.5	4.0	13.5	1.1
Piper	1	June 29	11.0	6.0	6.0	23.0	1.5
Sachs	1	July 2	43.5	38.5	16.5	98.5	0.8
Thurston	1	July 18	36.0	9.0	13.0	58.0	3.0
Talunkwan	1	July 19	10.3	3.0	12.0	25.3	1.2
Sconsar	1	July 19	6.5	2.0	0.5	9.0	0.3
Peel	1	July 29	3.0	3.0	1.0	7.0	0.3
Peel	2	July 29	4.0	0.0	4.0	8.0	0.8
		Old Logging, Mass Wasting					
Southday	1	June 8	0.5	1.5	0.5	2.5	0.2
Southday	2	June 8	0.0	0.0	0.0	0.0	0.0
Mosquito Lake	2	June 16	0.0	0.0	0.0	0.0	0.0
Two Torrent	1	June 17	4.5	1.0	0.0	5.5	0.3
Macmillan	1	July 16	0.0	0.0	0.0	0.0	0.0
Mosquito Ck. Trib.	1	July 22	78.0	8.0	1.5	77.5	1.8
Mountain	1	Aug 6	14.0	2.0	2.0	18.0	0.4
Saltspring	1	Aug 6	17.0	8.0	1.0	26.0	2.9
Saltspring	2	Aug 6	2.0	2.0	0.0	4.0	0.4
		New Logging, No Mass Wasting					
Tarundl	2	June 7	10.0	3.0	6.0	19.0	0.7
Riley Trib.	1	July 12	5.5	6.0	11.0	22.5	1.0
Riley	1	July 26	43.0	23.0	1.0	67.0	3.2
		New Logging, Mass Wasting					
Bonanza	1	July 9	38.0	4.0	0.0	42.0	1.0
Shelley	1	July 11	17.0	0.0	5.0	22.0	1.2
Riley	2	July 26	19.2	0.0	0.0	19.3	0.5

TABLE A7. Large organic debris cover in Queen Charlotte Island study streams, June 9-August 13, 1982

Stream	Reach	Date	Large Organic Debris (m^2) Pool	Glide	Riffle	Total	% of Total Wetted Area
		Unlogged, No Mass Wasting					
Rennell Unnamed	1	June 12	14.0	20.5	51.0	85.5	2.9
Matheson Side	1	June 22	114.0	26.5	9.5	150.0	7.7
Windy Bay Trib.	1	June 24	9.5	6.0	35.0	50.5	11.6
Windy Bay Trib.	2	June 24	49.0	40.0	21.5	110.5	13.2
Skaat	1	June 24	14.5	3.0	70.0	87.5	13.8
Matheson Head	1	July 11	285.5	47.0	19.4	351.9	9.3
Cache	1	July 12	141.0	57.0	28.0	226.0	13.1
Cache	2	July 12	83.0	12.0	45.0	140.0	11.0
Hangover	1	July 12	950.0	126.0	46.0	1122.0	13.6
Marshall Head	1	July 12	92.0	13.9	158.0	263.0	13.4
Government	1	July 26	858.0	45.0	51.0	954.0	26.5
Inskip	1	July 30	228.0	61.0	140.0	429.0	11.0
Government Trib.	1	Aug 7	75.0	4.5	10.0	89.5	10.5
Phantom	1	Aug 12	328.0	149.5	82.0	559.5	9.8
Salmon	1	Aug 13	42.0	120.0	116.0	278.0	2.5
		Unlogged, Mass Wasting					
Government Trib.	2	Aug 7	1.0	0.0	1.0	2.0	0.3
		Old Logging, No Mass Wasting					
Tarundl	1	June 6	626.0	98.5	32.0	756.5	10.0
Landrick	1	June 21	64.0	14.0	27.5	105.5	8.6
Piper	1	June 29	37.5	12.5	10.0	60.0	3.8
Sachs	1	July 2	486.0	168.0	162.0	816.0	6.3
Thurston	1	July 18	148.0	18.0	18.0	184.0	9.4
Talunkwan	1	July 19	47.0	10.0	16.0	73.0	3.4
Schomar	1	July 19	142.5	37.0	5.5	185.0	6.6
Peel	1	July 29	201.0	10.0	11.0	222.0	9.7
Peel	2	July 29	66.0	1.0	28.0	95.0	9.8
		Old Logging, Mass Wasting					
Southbay	1	June 8	15.5	8.0	21.5	45.0	2.6
Southbay	2	June 8	2.5	0.0	11.5	14.0	1.7
Mosquito Lake	2	June 16	19.5	1.0	0.0	20.5	4.2
Two Torrent	1	June 17	30.0	6.5	3.5	40.0	1.8
Macmillan	1	July 16	7.0	0.0	6.0	13.0	1.0
Mosquito Ck. Trib.	1	July 22	379.5	52.5	34.5	466.5	11.1
Mountain	1	Aug 6	44.0	0.5	10.0	54.5	1.2
Saltspring	1	Aug 6	32.0	7.0	8.0	47.0	5.2
Saltspring	2	Aug 6	17.0	2.0	4.0	23.0	2.4
		New Logging, No Mass Wasting					
Tarundl	2	June 7	53.0	13.5	72.0	138.5	4.9
Riley Trib.	1	July 12	56.0	26.0	135.5	217.5	9.2
Riley	1	July 26	317.0	55.0	7.5	379.5	18.0
		New Logging, Mass Wasting					
Bonanza	1	July 9	483.0	56.0	18.5	557.5	13.4
Shelley	1	July 11	38.0	8.0	17.0	63.0	3.5
Riley	2	July 26	228.5	62.0	46.5	337.0	9.0